Project Execution Plan

for the

Low Energy RHIC electron Cooling Accelerator Improvement Project (LEReC AIP)

at the

Brookhaven National Laboratory
Upton, NY

Office of Nuclear Physics (SC – 26)
Office of Science
U.S. Department of Energy

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1.0 INTRODUCTION

This Project Execution Plan (PEP) describes the coordination of efforts of the project team, including the processes and procedures used by the Low Energy RHIC electron Cooling (LEReC) Contractor Project Manager (CPM) to ensure that the project is completed on time and within budget. The PEP defines the project scope and the organizational framework, identifies roles and responsibilities of contributors, and presents the work breakdown structure (WBS), cost and schedule. The PEP was prepared using guidelines from DOE Order 413.3B, Program and Project Management for the Acquisition of Capital Assets*.*

1.1 Project Background

Brookhaven National Laboratory (BNL), located in Upton, NY, is owned by the U.S. Department of Energy (DOE) and operated by Brookhaven Science Associates (BSA) under the U.S. Department of Energy Contract No. DE-SC0012704. The flagship Nuclear Physics facility at BNL is the Relativistic Heavy Ion Collider (RHIC).

1.2 Justification of Mission Need

The mission of the Nuclear Physics (NP) program is to understand the evolution and structure of nuclear matter from the smallest building blocks, quarks and gluons, to the elements in the universe created by stars. A main objective of this nuclear science field is the identification and characterization of the properties of the strongly-coupled quark gluon plasma (QGP) that is produced in RHIC collisions and is believed to have filled the universe about a millionth of a second after the "Big Bang." The program provides world-class peer-reviewed research results in the scientific disciplines encompassed by the Nuclear Physics mission areas under the mandate provided in Public Law 95-91 that established the Department. The LEReC project directly supports the NP mission and will allow researchers to explore fundamental questions into the nature of the Quantum Chromo Dynamics (QCD) at RHIC.

The study of QCD phase structure is one of the most important tasks for the RHIC facility. Bulk matter in which the interactions are governed by QCD has a rich phase structure, which can be explored by varying the collision energy between heavy nuclei. In collisions of two nuclei, versus collisions of nuclei with their antimatter partner, the matter is formed with a net baryon density, or baryochemical potential, which decreases with increasing collision energy. At zero baryochemical potential, lattice gauge calculations have established that the transition from normal nuclear matter to the QGP is of the crossover type, in which no thermodynamic quantity diverges even in the infinite volume limit. At high baryochemical potential and low temperature, the transition is strongly first order, which leads to the conjecture that there must be a critical endpoint in the QCD phase diagram. In recent years lattice calculations have been extended to finite baryochemical potential, with many of these calculations finding a critical endpoint, though its location (and even its existence) is highly uncertain due to the difficulty of performing lattice calculations in this regime. The identification of the QCD critical point is therefore presently an experimental question: should it be found, its location and existence would provide a unique landmark in the understanding of the QCD phase diagram from first principles.

A first-phase scan over the lower end of the energy range was performed in RHIC in 2010-2011 and completed in 2014. This scan indicates that RHIC sits at a "sweet spot" in energy, in which rapid changes occur in a number of several observables. Combined, these measurements provide a substantial hint that collisions at energies at the lower range available at RHIC probe a region of non-trivial structure in the QCD phase diagram. However, many of these measurements are of limited statistical power. In order to convert these into conclusive statements, more luminosity is needed. As an upgrade to RHIC, LEReC promises to provide up to an order of magnitude higher luminosity for center of mass energies < 20 GeV per nucleon pair, where the location of QCD critical point is expected.

2.0 PROJECT SCOPE

This section describes the project in terms of the scope, cost, schedule and funding profile.

2.1 Scope Baseline

The addition of the LEReC will extend the unique capabilities of the beam-energy scan program at RHIC with unparalleled discovery potential to establish the location of the QCD critical point and to chart out the transition region from hadronic to deconfined matter.

2.1.1 Technical Scope

The project will use an electron beam to increase the RHIC luminosity, the prime measurement of RHIC performance, for operation with heavy ions at low energies. In this well-known electron cooling technique, an electron beam propagates with the same velocity as the ions for a small fraction of collider circumference – the cooling section – allowing the ions to give up some of their thermal kinetic energy to the electron beam.

The project will include an electron accelerator that provides beam with a maximum energy of 2 MeV for the Phase-I of the project (upgradable to higher energies with a 5-cell SRF and energy recovery linear accelerator (ERL) mode of operation, Phase-II), and electron beam transport lines that include focusing elements and bending magnets. These magnets merge the electron beam with the RHIC ion beams in both RHIC rings (Blue and Yellow) and then extract the electron beam into the dump.

The accelerator design for the Phase-I of the project is compatible with the use of either the DC photoemission gun or the SRF gun as the source of the electrons. Although beam dynamics manipulation is somewhat different depending on whether the DC or the SRF gun is used, the same hardware is suitable for both approaches. The DC gun is presently under contract with the Cornell University while commissioning of the SRF gun continues at the R&D Energy Recovery Linac (ERL) facility at BNL. For the DC gun option, the SRF gun will be used as a booster cavity. The SRF gun and the 5-cell cavity will be moved to RHIC and installed in the Interaction Region 2 (IR2) as well as beam diagnostic hardware, quadrupole magnets, power supplies and the beam dump. They will use the same cryogenic system as the Coherent Electron Cooling Proof-of-

Principle (CeC PoP) experiment. Two electron-cooling sections (one for the Yellow and one for the Blue RHIC ring) will be located in the warm part of Sector 1.

The electron beam line starts with the DC photoemission gun located near Interaction Point 2 (IP2) and goes towards the cooling sections in Sector 1 (left region in Figs. 1 and 2). After cooling ions in both the Blue and Yellow RHIC sections, the beam is extracted to the dump. For the DC gun option the 704 MHz SRF gun cavity will be used as a booster cavity, as shown in Fig. 1. A backup approach with the electron source being the SRF gun is shown in Fig. 2.

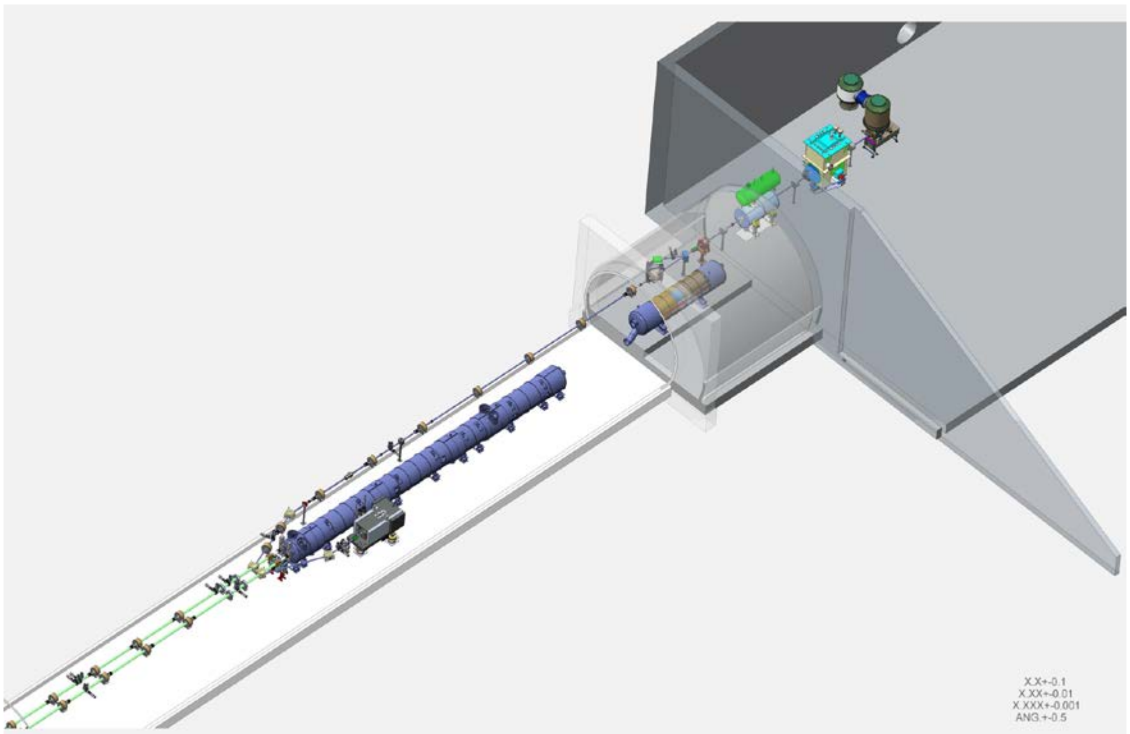


Figure 1: Layout of LEReC with the DC gun option and the SRF gun cavity used as a booster cavity (starting at right: DC gun, SRF booster cavity, 5-cell SRF cavity, electron beam transport lines, cooling sections, beam dump).

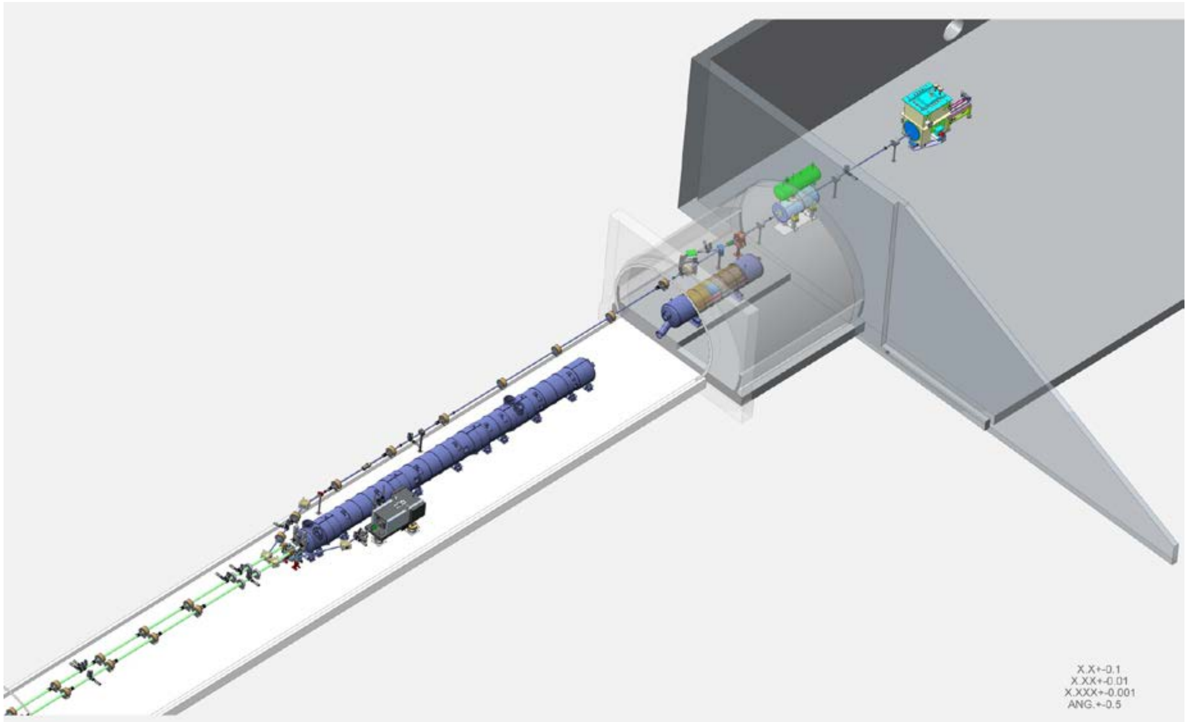


Figure 2: Layout of LEReC with the SRF gun option (starting at right: 704 MHz SRF gun, 5-cell SRF cavity, electron beam transport lines, cooling sections, beam dump).

Support equipment will be located in buildings 1002A and 1002B. A laser building has been already installed for the CeC PoP experiment and will be used for the LEReC project as well (1002C or 1002E). Building 1002D (previously used for BRAHMS – Broad Range Hadron Spectrometers Experiment) will be used for power supplies and controls equipment that do not fit in the 1002A and 1002B buildings.

The Electron Cooler will consist of:

1. A DC photoemission electron gun with beam energy of 400 keV and the SRF booster cavity (the 704 MHz SRF booster cavity is presently being commissioned as the photoemission gun in R&D ERL and could be used as electron source if stable operation with all needed parameter is demonstrated).
2. A 704 MHz 5-cell SRF cavity to produce energy chirp for bunch stretching (this cavity will be used for acceleration in the ERL mode for LEReC Phase-II – an energy upgrade up to 5 MeV). For the option based on the DC gun sufficient energy chirp can be produced with the booster cavity making installation of the 5-cell cavity for the Phase-I not critical.
3. A 9 MHz warm cavity to correct beam loading in the 5-cell SRF cavity.
4. A 704 MHz warm cavity to correct the energy spread after bunches are stretched.
5. A 2110.7 MHz warm cavity (3^{rd} harmonic of 704 MHz) for energy spread correction.
6. Electron beam transport to the cooling sections in Sector 1.

7. A cooling section in RHIC Yellow ring, about 20 m long. Short focusing solenoids are located every 3 m. The free space between the solenoids is covered by several layers of mu-metal to shield the magnetic field in the cooling section to the required level.
8. U-turn 180 degrees dipole magnet between the Yellow and Blue ring cooling sections.
9. A cooling section in the RHIC Blue ring.
10. An extraction line and beam dump.

The LEReC electron accelerator:

Kinetic energies up to 2 MeV will be provided by the DC gun with the SRF booster cavity (or the SRF gun). The DC gun, identical to the one presently in operation at Cornell University which is shown in Fig. 3, will be built for LEReC by Cornell University. Funding of acquisition of this DC gun for LEReC is not part of this LEReC AIP project.

This will be followed by an energy upgrade (Phase-II) where 5-cell SRF cavity will be used to accelerate electrons to 5 MeV in Energy Recovery Linac (ERL) mode. The transport beam lines to and from the cooling sections will be reconfigured for the ERL mode.

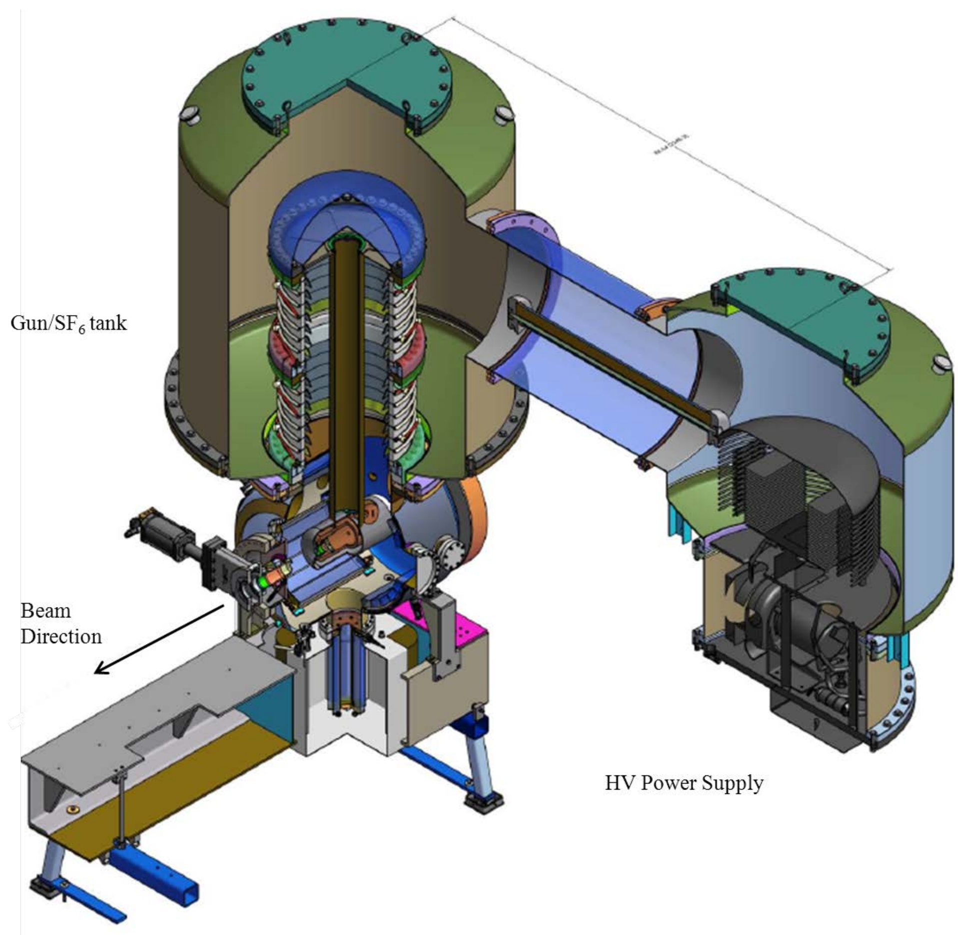


Figure 3: The DC gun at Cornell University (courtesy of Cornell University).

The layout of the 704 MHz SRF gun is shown in Figure 4. At present, it is being commissioned at the R&D ERL facility. The same gun could be converted for use as a booster cavity of the DC gun option. Figure 3a shows the gun cryomodule installed in the ERL blockhouse. The half-cell gun was designed to operate at an accelerating voltage of up to 2 MV with a beam current ten times larger than planned for LEReC operation. This provides a very good safety margin. The electron beam is generated in the gun by illuminating a K_2CsSb photocathode with green (532 nm) light from a laser.

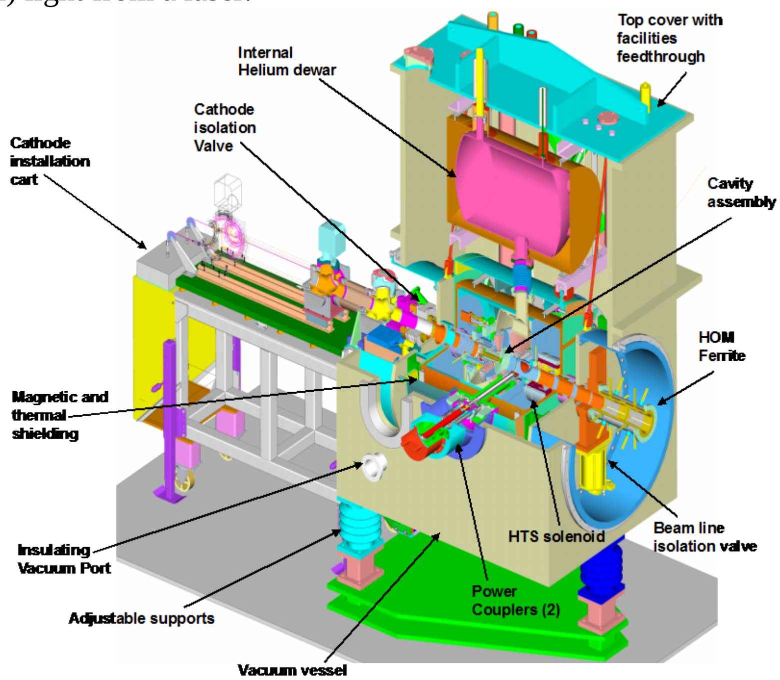


Figure 4: The 704 MHz SRF gun cryomodule.

Figure 5: 704 MHz SRF gun installed in the R&D ERL blockhouse for commissioning.

The required CW beam current (up to 50 mA) and charge per bunch (up to 300pC) has been already demonstrated in the DC gun which is in operation at Cornell. The required current and beam parameters from the 704 MHz SRF gun which is presently under commissioning at BNL is yet to be demonstrated.

Several types of high QE photocathodes are presently used in photoemission guns, including GaAs(Cs), Cs_2Te, and K_2CsSb. Cesium potassium antimonide is the preferred option at present. K_2CsSb cathodes are more robust than gallium arsenide cathodes as they have a very long lifetime and can be transported without much performance degradation. In addition they have higher QE than cesium telluride cathodes and can be used with green lasers whereas CsTe photocathodes require UV light.

For LEReC Phase-I, the gun (DC or SRF) has to operate with 100 pC bunch charges and 30 mA average beam current. For the energy upgrade LEReC Phase-II, the gun has to operate with 300 pC and 50 mA beam current.

The gun will produce bunch trains with individual electron bunches of 50 ps full length at a bunch train repetition frequency of 9 MHz, the same as the RHIC ion bunch repetition frequency. An optical system will allow the creation of dedicated bunch patterns for different RHIC energies and ion bunch lengths. Each bunch train will be followed by a 100 ns long gap corresponding to the gap between ion bunches, as illustrated in Figures 6-7.

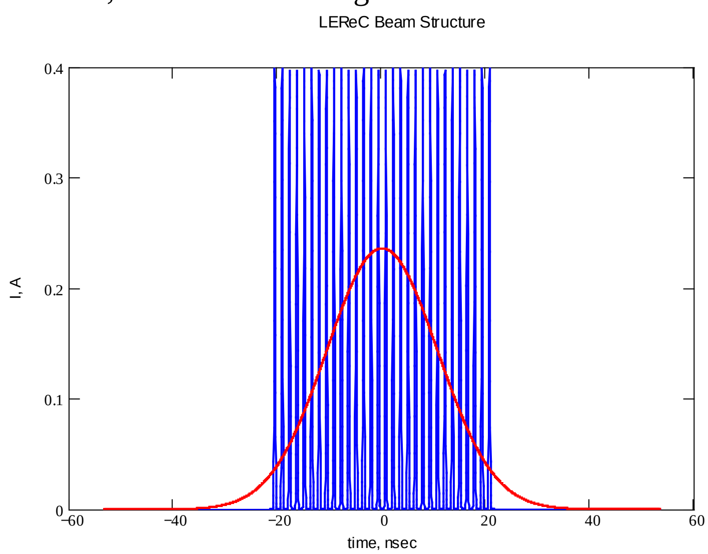


Figure 6: Thirty electron bunches (blue) placed on a single ion bunch (red). Example for long bunches with 9 MHz RHIC RF at $\gamma = 4.1$.

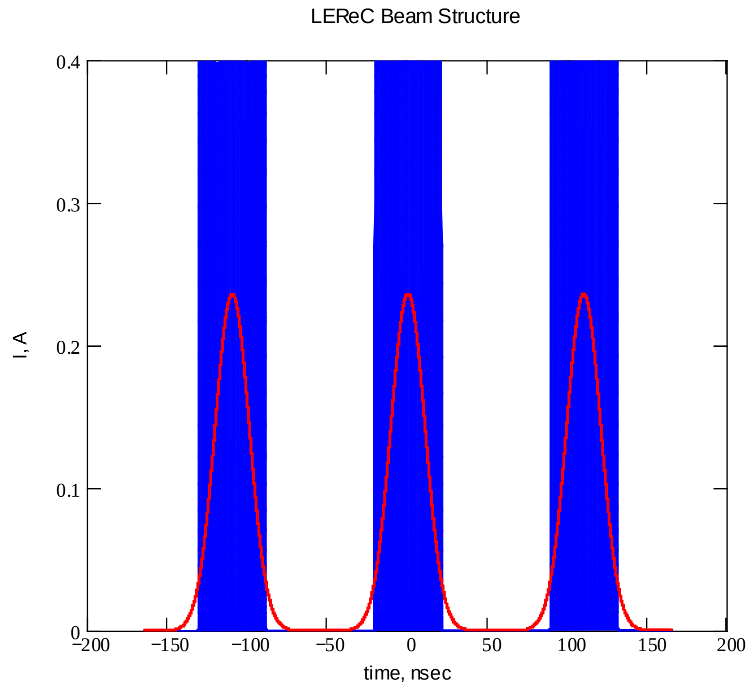


Figure 7: Three RHIC bunches (red) with thirty electron bunches (blue) each. Example for long bunches with 9 MHz RHIC RF at $\gamma = 4.1$.

The SRF gun was designed for a higher beam current and power with an external quality factor (Q_{ext}) of the FPCs currently set to 5.8×10^4. For the most efficient use of RF power in LEReC, the Q_{ext} should be set to 3.4×10^5. As the FPCs on the gun are not adjustable, the coupling needs to be changed either by modifying the FPCs or by external means.

For compensating beam space charge, a high-temperature superconducting solenoid (HTSS) is installed inside the gun. At present, cooling of the solenoid current leads is inadequate and does not allow operation at the design field in CW mode as is required for LEReC. The cooling improvement is included in our plans of refurbishing the SRF gun. The refurbishing will be completed and the gun will be re-commissioned in the ERL facility prior to its installation in the RHIC tunnel for LEReC operation.

The five-cell SRF cavity (named “BNL1”) is currently installed in the ERL facility. The BNL1 cryomodule layout is shown in Figure 8. It is commissioned to operate in CW mode with an accelerating voltage up to 12 MV. This is much higher than the maximum voltage required even for LEReC energy upgrade of 3.3 MV. No modifications of this system are required for use in LEReC. The RF power to the five-cell cavity will be provided from a 20-kW solid-state RF amplifier, which will be shared with the CeC PoP experiment.

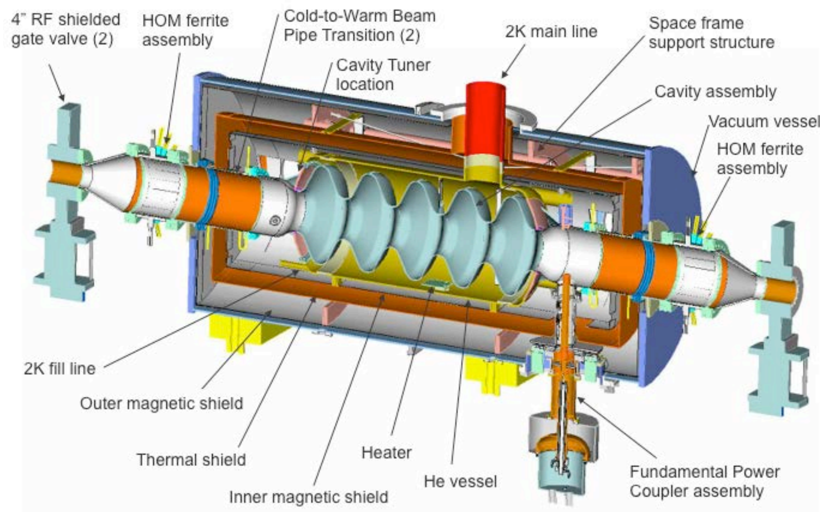


Figure 8: The BNL1 cavity cryomodule.

A special third harmonic (2.1 GHz) cavity will be used for energy spread correction of electron beam. This cavity will be normal conducting as the required voltage is not very high.

2.1.2 Technical Performance Parameters

An upgrade of the RHIC RF with a new 9 MHz system (3 cavities per ring, 60 kV gap voltage per cavity), which will allow the use of longer bunches, is presently under way. The electron beam parameters presented below are given based on the cooling of ions beams with such new 9 MHz RHIC RF system. Depending on the beam energy and longitudinal emittance, the ion beam will have a rms longitudinal momentum spread in the range of $\sigma_p = 4\text{-}5\times10^{-4}$. This sets a limit on the rms momentum spread of the electron beam of about 5×10^{-4}. The requirement for the transverse angles of electron beam in the cooling sections is given by the angular spread of the ion beam in the cooling section and is 150 μrad at $\gamma = 4.1$, for example. An emittance contribution to the transverse angles sets the requirement for the normalized electron beam rms emittance to < 2.5 mm mrad.

The electron beam parameters needed to achieve the maximum cooling performance are summarized in Table 2-2. With a reduced charge per bunch or larger momentum spread or larger emittance, the cooling factors sufficient for the physics program can still be achieved, as indicated in the Ultimate Performance Parameters listed after the Table 2-3. As such, beam parameters shown in Table 2-2 represent a desired goal rather than a strict requirement needed for cooling performance consistent with physics expectations. The electron beam parameters in Table 2-2 provide for a safety margin of a factor of 2 over what is needed for the UPPs.

To represent the cooling factor dependence on the electron beam velocity spreads, contour plots of the cooling force components for fixed ion velocity corresponding to the rms velocity spread of ion beam (for ion beam rms normalized emittance of 2.5 mm mrad and rms momentum spread of 0.0005) are plotted as a function of electron beam emittance and momentum spread in Figs. 9-10.

The cooling force is normalized to the baseline electron beam parameters with the rms normalized emittance of 2.5 mm mrad and rms momentum spread of 0.0005. A value of the cooling force less than unity corresponds to cooling factor reduction due to the electron beam parameters below the requirement. The values larger than unity correspond to cooling improvement.

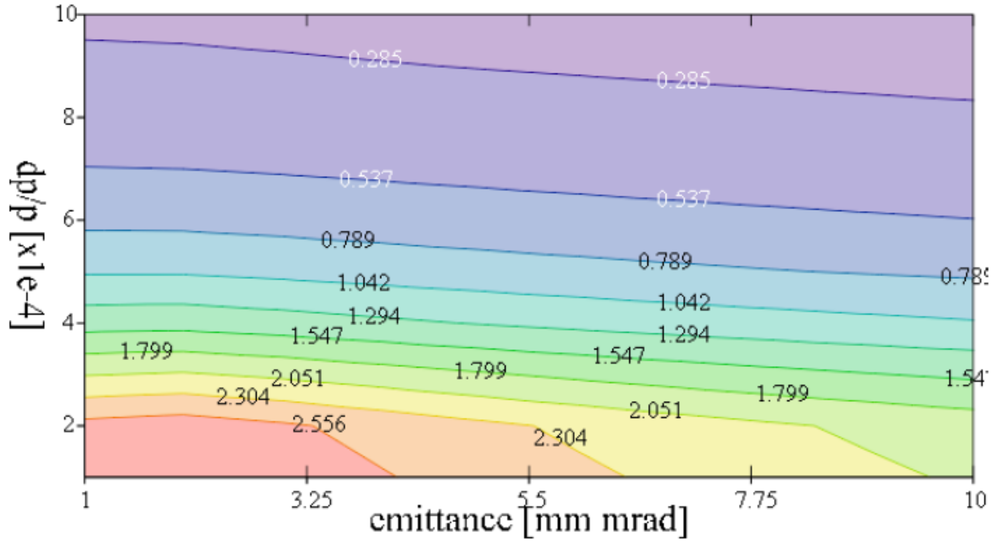


Figure 9: Longitudinal component of the friction force for the ion velocities corresponding to the rms of ion beam distribution as a function of electron beam rms emittance and rms momentum spread.

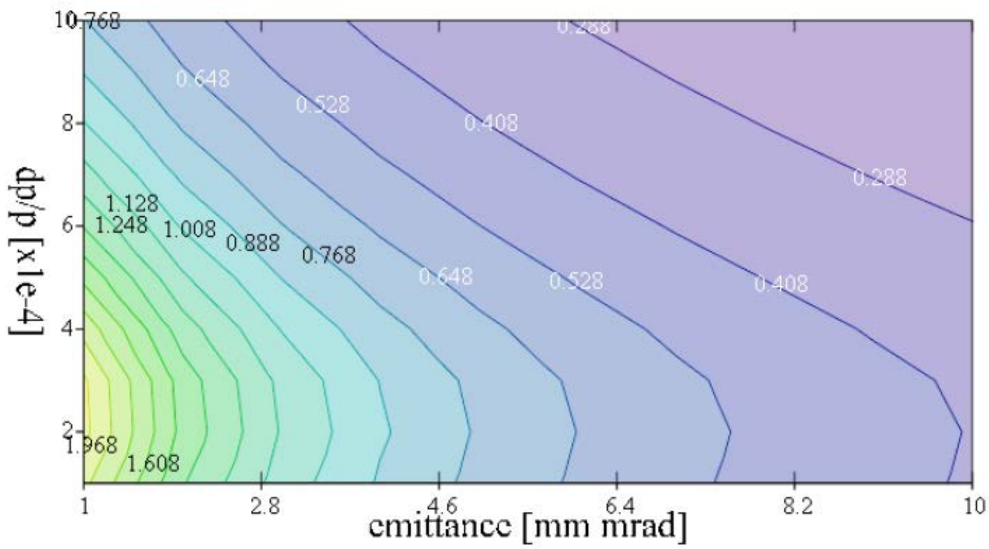


Figure 10: Transverse component of the friction force for the ion velocities corresponding to the rms of ion beam distribution as a function of electron beam rms emittance and rms momentum spread.

Beam dynamics simulations were performed with bunch charges larger than in Table 2-2 (up to 30 %) to establish the good portion of the electron bunch distribution which corresponds to the parameters required for maximum cooling performance. Engineering design takes into account the possibility of operation with such higher beam charges.

Table 2-2: Electron beam parameters for LEReC Phase-I (up to 2 MeV; example is given for 1.6 MeV) and LEReC Phase-II (up to 5 MeV).

	LEReC-I (up to 2 MeV)	**LEReC-II (up to 5 MeV)**
Lorentz factor	4.1	10.7
RHIC RF frequency, MHz	9.10	9.34
Electron beam kinetic energy, MeV	1.6	4.96
Total charge per bunch train, nC	3 (30 bunches)	5.4 (18 bunches)
Momentum spread $\sigma_p = \Delta p/p$, rms	5×10^{-4}	5×10^{-4}
Normalized rms emittance, μm	2.5	2.5
Transverse rms beam size, mm	4.3	2.6
Average beam current, mA	27	50

Table 2-3: Parameters of LEReC Phase-I accelerator with DC gun option (up to 2 MeV; example is given for final kinetic energy of 1.6 MeV).

	LEReC-I (up to 2 MeV)
Lorentz factor	4.1
Electron beam kinetic energy	1.6 MeV
DC photoemission gun	
Gun voltage (nominal operation)	400 kV
704 MHz SRF booster	
SRF frequency	703.59 MHz
Gun voltage	1.2 MV
R/Q	96.2 Ω
Geometry factor	112.7 Ω
Cavity *Q* factor at 2 K	1.1×10^{10}

External *Q* factor	$3.4{\times}10^5$
RF power	36 kW
Single cell 704 MHz copper cavity	
Cavity voltage	430 kV
R_{sh}	7.25 MΩ
R/Q	250 Ω
RF power	25 kW
Third harmonic 3-cell copper cavity	
Third harmonic frequency	2110.8 MHz
Cavity voltage	100 kV
R_{sh}	5.7 MΩ
R/Q	487 Ω
RF power	5.5 kW
Photocathode laser	
Wavelength	532 nm
Average optical power on cathode (@1%QE)	6.5 W
Design average power (Green)	60 W

Table 2-4: Parameters of LEReC Phase-I accelerator with the SRF gun option (up to 2 MeV; example is given for 1.6 MeV).

	LEReC-I (up to 2 MeV)
Lorentz factor	4.1
Electron beam kinetic energy	1.6 MeV
704 MHz SRF gun	
SRF frequency	703.59 MHz
Gun voltage	1.6 MV
Peak electric field E_{pk}	30.3 MV/m
R/Q	96.2 Ω
Geometry factor	112.7 Ω

Cavity *Q* factor at 2 K	1.1×10^{10}
External *Q* factor	3.4×10^{5}
RF power	48 kW
704 MHz 5-cell SRF cavity	
Cavity voltage	0.155 MV
R/Q	404 Ω
Geometry factor	225 Ω
Cavity *Q* factor at 2 K	2.2×10^{10}
External *Q* factor	2×10^{7}
RF power	3kW(installed 20 kW)
Single cell 704 MHz copper cavity	
Cavity voltage	430 kV
R_{sh}	7.25 MΩ
R/Q	250 Ω
RF power	25 kW
Third harmonic 3-cell copper cavity	
Third harmonic frequency	2110.8 MHz
Cavity voltage	100 kV
R_{sh}	5.7 MΩ
	487 Ω
R/Q	
RF power	5.5 kW
Photocathode laser	
Wavelength	532 nm
Average optical power on cathode (@1%QE)	61.52 W
Design average power (green)	60 W

LEReC Key Performance Parameters (KPPs):

1. Demonstration of 30 mA average electron beam current with charges of 100 pC per bunch from the selected gun (SRF or DC) in stable operation.

2. All LEReC hardware (from the gun to the beam dump) installed in its final location in RHIC Interaction Region 2.

3. Beam transport of 1 mA electron current at an energy of 1.6 MV through the full LEReC beam transport system from the gun through both of the cooling sections and extraction to the beam dump.

4. Demonstration of electron beam parameters in a cooling section suitable for cooling commissioning, i.e. rms momentum spread $< 1.5\times10^{-3}$ and rms normalized emittance < 3.5 μm.

5. Demonstration cathode lifetime 1/e of 24 hours for 30 mA average beam current.

6. Demonstration of initial cathode Quantum Efficiency of 1%.

LEReC Ultimate Performance Parameters (UPPs), represent parameters required for cooling demonstration with configuration of electron accelerator in RHIC tunnel at IP2:

1. Demonstration of 30 mA average electron beam current in stable CW operation in full LEReC configuration in RHIC tunnel at energies of 1.6-2 MeV.

2. Achieving electron beam parameters in both cooling sections required for cooling and luminosity improvement: rms energy spread of $< 1\times10^{-3}$ and rms normalized emittance of < 3 μm for good portion of electron bunch which contains bunch charge of about 100 pC.

3. Demonstration of the electron cooling process of the ion bunches with a bunched electron beam.

4. Demonstration of cathode lifetime 1/e of 2-3 days to provide for smooth RHIC operations.

5. Demonstration of initial cathode Quantum Efficiency of 5%.

6. Luminosity increase of a factor of four compared to the one delivered in Beam Energy Scan Phase-I physics program (with new 9 MHz RHIC RF system which is presently under construction).

2.2 Cost Baseline by Work Breakdown Structure (WBS)

The LEReC has been organized into a WBS for purposes of planning, managing and reporting project activities. Project Management efforts are distributed throughout the project, including conceptual design and R&D. A WBS Dictionary is provided in Appendix A of this document.

The estimated cost including contingency is $8.3M. Table 2-3 shows the cost summary in AY K dollars. Estimate based contingency plus Risk based contingency total $1.6M (23.9%) of the estimate.

		AY $K
WBS	**Name**	**Cost**
1.0	**Low Energy RHIC electron Cooling (LEReC)**	
1.1	Project Management	496
1.2	Physics Support*	0
1.3	Gun and Cavities	1352
1.4	RF Amplifiers and LLRF	1432
1.5	Magnets	867
1.6	Power Supplies	270
1.7	Beam Instrumentation	890
1.8	Beam Dump	41
1.9	Beam Line Vacuum	719
1.10	Controls	265
1.11	Cryogenic Systems	96
1.12	Installation	289
1.13	Commissioning*	0
	Total Estimated Cost	6716
	Bottom up Contingency	1305
	Risk Register	300
	Total Project Cost	8321
	total risk and contingency	1605
	as a % of planned costs	23.9%
*	funded by RHIC Operations	

Table 2-3 Cost Summary in AY K$

Cost estimates were developed from a bottom-up analysis of each contribution to the scope of the LEReC project with contingency funds as an allowance for uncertainties, omissions, and risks. Contingency by subsystem is shown in Table 2-4 below.

		AY $K		
WBS	**Name**	**Cost**	**Contingency $**	**Contingency %**
1.0	**Low Energy RHIC electron Cooling (LEReC)**			
1.1	Project Management	496	0	0
1.2	Physics Support*	0	0	0
1.3	Gun and Cavities	1352	462	34%
1.4	RF Amplifiers and LLRF	1432	87	6%
1.5	Magnets	867	130	15%
1.6	Power Supplies	270	62	23%
1.7	Beam Instrumentation	890	383	43%
1.8	Beam Dump	41	3	8%
1.9	Beam Line Vacuum	719	43	6%
1.10	Controls	265	10	4%
1.11	Cryogenic Systems	96	41	43%
1.12	Installation	289	85	30%
1.13	Commissioning*	0	0	0
	Total Estimated Cost	6716		
	Bottom up Contingency	1305	1305	
	Risk Register	300		
	Total Project Cost	8321		
*	funded by RHIC Operations			
Cost estimates were developed from a bottom-up analysis of each contribution to the scope of the LEReC project with contingency funds as an allowance for uncertainties, omissions and risks.				

Table 2-4 Contingency by Subsystem

2.3 Schedule Baseline and Critical Path

The schedule is constrained by several things:
RHIC shutdowns - installation in the tunnel is only possibly when RHIC is not running.
Installation complete – during this time subsystem testing will occur and activities related to the Accelerator Readiness Review will occur.
Commissioning – testing with beam may not begin until approval to do so is granted by the DOE site office.

The High Level Early Finish schedule is shown below, followed by the Critical Path. There are 9 months of float from the Project Early Finish date to the Project Finish Reportable Milestone.

	WBS	Name	Cost	Start	Finish
0	1.	Low Energy RHIC electron Cooling (LEReC)	$6,716,291	Fri 8/15/14	Sun 9/30/18
1	1.1	Project Management	$496,034	Mon 9/15/14	Sun 9/30/18
15	1.2	Physics Support	$0	Mon 9/15/14	Fri 9/28/18
40	1.3	Gun & Cavities	$1,352,262	Mon 9/15/14	Mon 7/3/17
221	1.4	RF Amplifiers & LLRF	$1,432,417	Mon 9/15/14	Mon 8/28/17
277	1.5	Magnets	$866,842	Fri 8/15/14	Wed 4/19/17
380	1.6	Power Supplies	$269,846	Thu 10/15/15	Tue 3/28/17
406	1.7	Beam Instrumentation	$889,977	Mon 9/15/14	Tue 3/13/18
562	1.8	Beam Dump	$40,518	Mon 1/4/16	Wed 6/14/17
595	1.9	Beam Line Vacuum	$718,642	Mon 9/15/14	Mon 4/17/17
710	1.10	Controls	$264,907	Mon 8/17/15	Wed 3/29/17
941	1.11	Cryogenic Systems	$95,649	Tue 4/21/15	Tue 12/6/16
1063	1.12	Civil Construction & Installation	$289,197	Mon 9/15/14	Tue 3/13/18
1571	1.13	Commissioning	$0	Tue 1/3/17	Sun 9/30/18

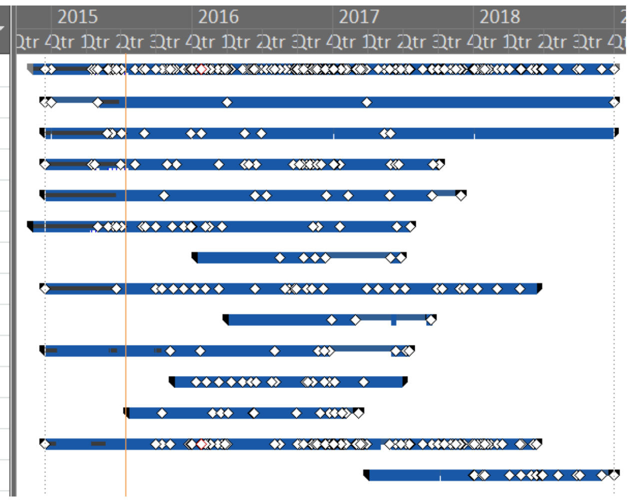
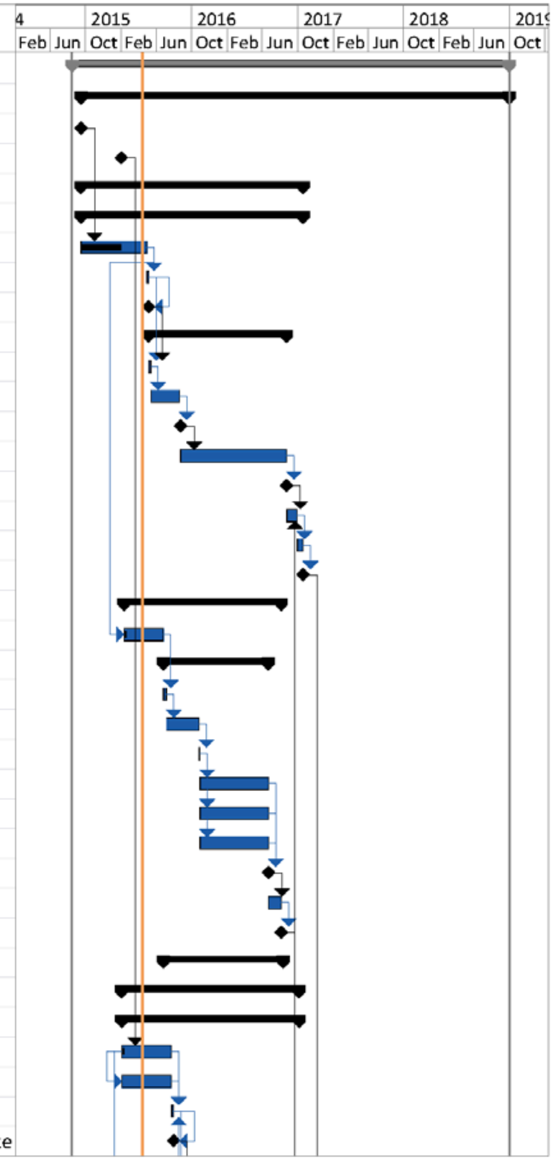
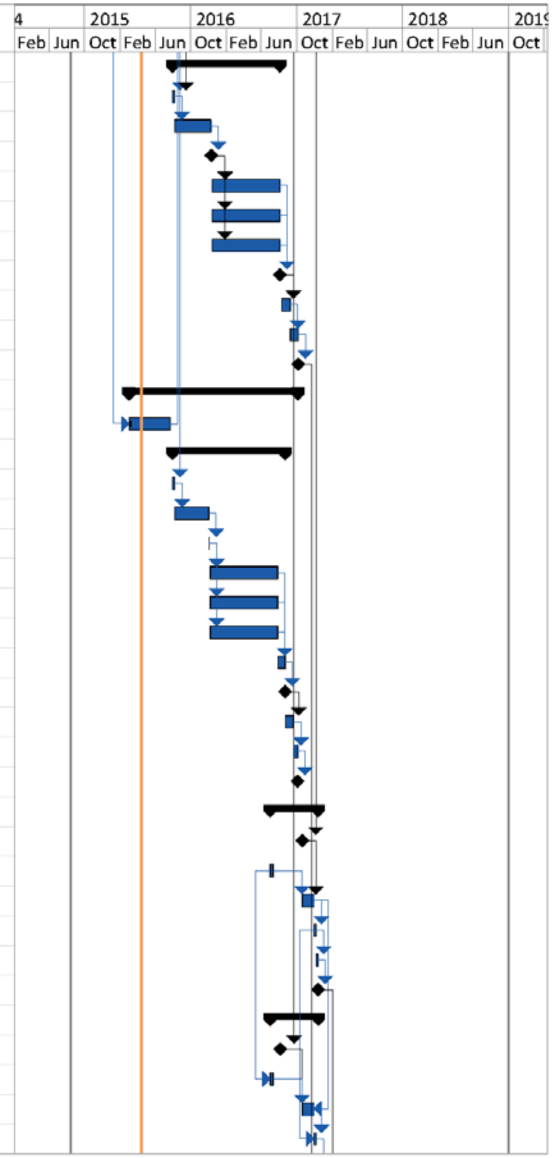


Figure 11: Summary Schedule

ID	WBS	Task Name
0	**1.**	**Low Energy RHIC electron Cooling (LEReC)**
1	**1.1**	**Project Management**
2	1.1.1	High Priority Items Start
3	1.1.2	Full Project Design Start
141	**1.3.8**	**2.1 GHz Warm Cavity**
142	**1.3.8.1**	**2.1 GHz Warm Cavity Design and Fabrication**
143	1.3.8.1.1	2.1 GHz Warm Cavity Design
144	1.3.8.1.2	2.1 GHz Warm Cavity, Tuner & Support Sytem Design Review & Approval
145	1.3.8.1.3	2.1 GHz Warm Cavity, Tuner & Support Sytem Design Review & Approval Complete
146	**1.3.8.1.4**	**Procurement**
147	1.3.8.1.4.1	2.1GHz Warm cavity Specifications, SOW, Vendor Requisition and Support (Note)
148	1.3.8.1.4.2	RFQ Bids Issued, Returned & Evaluated
149	1.3.8.1.4.3	2.1GHz Warm Cavity Purchase Orders Awarded
150	1.3.8.1.4.4	2.1 GHz Warm Cavity Purchase (Note)
153	1.3.8.1.4.7	All 2.1 GHz Warm Cavity Purchases Received & Available for Assembly
154	1.3.8.1.5	Acceptance Test
155	1.3.8.1.6	2.1 GHz Warm Cavity Leak Test & Bake
156	1.3.8.1.7	2.1 GHz Warm Cavity Available for Installation
157	**1.3.8.2**	**2.1 GHz Warm Cavity Tuner System**
158	1.3.8.2.1	2.1 GHz Warm Cavity Tuner Design
159	**1.3.8.2.2**	**Procurement**
160	1.3.8.2.2.1	Specifications, SOW, Vendor Requisition and Support (Note)
161	1.3.8.2.2.2	RFQ Bids Issued, Returned & Evaluated
162	1.3.8.2.2.3	Purchase orders Awarded
163	1.3.8.2.2.4	Tuner Assembly (Qty 2)
164	1.3.8.2.2.5	Tuner Drive (Qty 2)
165	1.3.8.2.2.6	Cooling System
166	1.3.8.2.2.7	All 2.1 GHz Warm Cavity Tuner Purchases Received & Available for Assembly
167	1.3.8.2.3	Assembly & Test
168	1.3.8.2.4	2.1 GHz Cavity Tuner System Available for Installation
169	**1.3.8.3**	**2.1 GHz Warm Cavity Support Stand, Coax, Vacuum, Cooling Sys. & Misc**
180	**1.3.9**	**704 MHz Warm Cavity**
181	**1.3.9.1**	**704 MHz Warm Cavity**
182	1.3.9.1.1	704 MHz Warm Cavity Design (Note)
183	1.3.9.1.2	704 MHz Warm Cavity Design Consultant
184	1.3.9.1.3	704 MHz Warm Cavity, Tuner & Support System Design Review & Approval
185	1.3.9.1.4	704 MHz Warm Cavity, Tuner & Support System Design Review & Approval Complete



ID	WBS	Task Name
186	**1.3.9.1.5**	**Procurement**
187	1.3.9.1.5.1	Specifications, SOW, Vendor Requisition, Bid, Place & Support
188	1.3.9.1.5.2	RFQ Bids Issued, Returned & Evaluated
189	1.3.9.1.5.3	704MHz Warm Cavity Purchase orders Awarded
190	1.3.9.1.5.4	704 MHz Warm Cavity Purchase
191	1.3.9.1.5.5	RF Window (QTY 2) Purchase
192	1.3.9.1.5.6	FPC Modified Waveguide Purchase
193	1.3.9.1.5.7	All 704 MHz Warm Cavity Procurements Complete
194	1.3.9.1.6	System Assembly 704 MHz Cavity at BNL
195	1.3.9.1.7	Test 704 MHz Warm Cavity for Leakage
196	1.3.9.1.8	704 MHz Warm Cavity Available for Installation
197	**1.3.9.2**	**704 MHz Tuner System (Warm Cavity)**
198	1.3.9.2.1	704 MHz Tuner System (Warm Cavity) Design
199	**1.3.9.2.2**	**Procurement**
200	1.3.9.2.2.1	Specifications, SOW, Vendor Requisition, Bid, Place & Support
201	1.3.9.2.2.2	RFQ Bids Issued, Returned & Evaluated
202	1.3.9.2.2.3	Purchase orders Awarded
203	1.3.9.2.2.4	704 MHz Tuner Assembly Purchase
204	1.3.9.2.2.5	Tuner Drive (Qty 1)
205	1.3.9.2.2.6	Cooling System
206	1.3.9.2.2.7	Acceptance
207	1.3.9.2.2.8	All 704 MHz Tuner Sysem Procurements Complete
208	1.3.9.2.3	Tuner System Assembly
209	1.3.9.2.4	Tuner System Testing
210	1.3.9.2.5	704 MHz Warm Cavity Tuner Available for Installation
1203	**1.12.2.2.5**	**2.1 GHz Cavity**
1204	1.12.2.2.5.1	2.1 GHz Cavity & Stand Available for Installation
1205	1.12.2.2.5.2	Pre-Survey
1206	1.12.2.2.5.3	Install 2.1 GHz Cavity at IP2
1207	1.12.2.2.5.4	Survey
1208	1.12.2.2.5.5	30KW Water Chiller Available for Cavity Connections
1209	1.12.2.2.5.6	2.1 GHz Cavity Installation Complete with Water Chiller
1210	**1.12.2.2.6**	**2.1 GHz Cavity Tuner System**
1211	1.12.2.2.6.1	2.1 GHz Cavity Tuner System Available for Installation
1212	1.12.2.2.6.2	Pre-Survey
1213	1.12.2.2.6.3	Install 2.1 GHz Cavity Tuner System
1214	1.12.2.2.6.4	Survey



ID	WBS	Task Name
1215	1.12.2.2.6.5	Tuner Set & Test
1216	1.12.2.2.6.6	2.1 GHz Cavity Tuner System Installation Complete
1217	**1.12.2.2.7**	**704 MHz Warm Cavity**
1218	1.12.2.2.7.1	704 MHz Warm Cavity & Stand Available for Installation
1219	1.12.2.2.7.2	Pre-Survey
1220	1.12.2.2.7.3	Install 704 MHz Warm Cavity at IP2
1221	1.12.2.2.7.4	Survey
1222	1.12.2.2.7.5	20KW Water Chiller Available for Cavity Connections
1223	1.12.2.2.7.6	704 MHz Warm Cavity & Stand Installation Complete
1357	1.12.2.7.2	Vacuum Installation Complete Transport Line without 9 MHz Cavity Shutdown 2
1379	**1.12.2.7.10**	**2.1 GHz Cavity**
1380	1.12.2.7.10.1	All 2.1 GHz Purchases Received & Available for Installation
1381	1.12.2.7.10.2	Install of Stands and Misc. Brackets (Shops)
1382	1.12.2.7.10.3	2.1 GHz Cavity Vacuum Pumps, Valves, Piping, Jackets and Guages Installed
1383	1.12.2.7.10.4	2.1 GHz Cavity Vacuum System Installed
1384	**1.12.2.7.11**	**704 MHz Cavity**
1385	1.12.2.7.11.1	All 704 MHz Purchases Received & Available for Installation
1386	1.12.2.7.11.2	704 MHz Cavity Vacuum Pumps, Valves, Piping, Jackets and Guages Installed
1387	1.12.2.7.11.3	704 MHz Cavity Vacuum System Installed
1579	1.13.2.1	LEReC Sub-system installation Complete, Testing without Beam
1580	1.13.2.2	LEReC Sub-system installed, Tested without Beam Complete
1582	1.13.2.3.1	RHIC Run 2 Warm Cavity Commissioning and Conditioning
1583	1.13.2.3.2	Post RHIC Run Warm Cavity Assessment & Modification
1585	1.13.2.3.4	Beam Transport Line System Installation Complete, Ready for Testing
1587	1.13.2.3.6	Beam Transport Line Component Test Complete, Ready for Beam
1588	1.13.2.3.7	Warm Cavity Tests Complete, Ready for Conditioning and Commissioning (Shtdwn 3)
1589	1.13.2.3.8	Warm Cavity Conditioning and Commissioning, Ready for Beam (Shtdwn 3)
1597	1.13.3.1.1	Low Intensity Beam Testing Start
1598	1.13.3.1.2	DC Gun to SRF 1 Cell Cavity
1603	1.13.3.2.1	First Beam Test and Diagnostic with Beam Test
1604	1.13.3.2.2	Beam Profile Monitor Testing with Beam
1609	1.13.3.2.7	Beam Instrumentation Tested with Beam Complete
1615	1.13.3.2.13	High Intensity Beam Testing Start
1616	1.13.3.2.14	High Energy (Phase 1), High Intensity Beam to Beam Dump
1617	1.13.4	Commissioning Finish (Deadline 9/30/2018)
1618	1.13.5	Project Finish Date

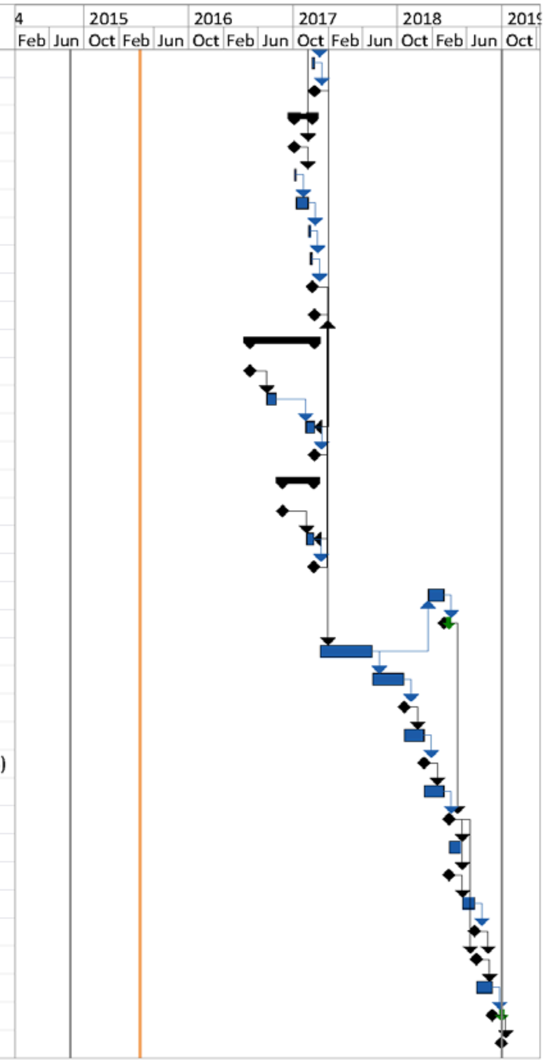


Figure 12: Critical Path.

2.3.1 Milestones

Milestones will be used as schedule events to mark the due date for accomplishment of a specified effort or objective. A milestone may mark the start, an interim step, or the end of one or more activities as needed to provide insight into the project's progress. The following table details the reportable milestones for the LEReC Phase I project. All milestones are maintained in the LEReC Microsoft Project cost and schedule database as Early Finish milestones. There is currently 9 months schedule float from the internal Project Complete milestone to the reportable milestone below.

Level	Reportable Milestones	Date
1	704 MHz Warm Cavity, Tuner & Support System Design Review & Approval Complete	4QFY15
1	Accelerator Section Physics Design Review	4QFY15
1	Extraction Line Lattice, Beam Instru., Beam Dump Physics Design Review	2QFY16
1	ERL Testing Complete, Equipment Extraction May Begin	2QFY17
1	DC Gun Available for Installation	3QFY17
1	SRF 1 Cell Cavity Commissioned w/Beam	4QFY18
1	Project Finish Date	3QFY19
2	Beam Dynamics Optimized for DC Gun	2QFY15 (A)
2	Laser Design Review Completed	2QFY15 (A)
2	Compensating Solenoids Contract Awarded	2QFY15 (A)
2	Matching Solenoids Specifications, SOW, Vendor Requisition and Support	2QFY15 (A)
2	Matching Solenoids Contract Awarded	2QFY15 (A)
2	Design Review for Beam Profile Monitor & Emittance & Energy Spread Slits System for RHIC Cooling Section, Shutdown 1	2QFY15 (A)
2	2.1 GHz Warm Cavity, Tuner & Support Sytem Design Review & Approval Complete	3QFY15
2	Magnet, 180° Dipole Contract Awarded	3QFY15
2	Laser Master Oscillators, Amplifier & Other Contract Award	4QFY15
2	2.1GHz Warm Cavity Purchase Orders Awarded	4QFY15
2	Power Amplifiers 704 MHz SCRF Booster Cavity (2 req'd) Contract Awarded	4QFY15
2	Magnet, 20° Dipole Contract Awarded	4QFY15
2	BPrM for RHIC Cooling, Purchase orders Awarded, Shutdown 1	4QFY15
2	Beamline Alignment/RF Phase/Stability Studies Complete	1QFY16
2	704MHz Warm Cavity Purchase orders Awarded	1QFY16
2	Compensating Solenoids Characterized & Available for Installation	1QFY16
2	Transport Lattice Physics Design Review	1QFY16
2	RHIC Shutdown 1 Deadline for LEReC Cooling Section Installation Complete	2QFY16
2	180° Dipole Magnet Characterized & Available for Installation	2QFY16
2	20° Dipole Magnet Characterized & Available for Installation	2QFY16
2	LEReC Safety Assessment Document Submitted	3QFY16
2	Beam Dump Diagnostic Design Review, Shutdown 3	3QFY16
2	Power Amplifier (1 req'd) Rec'd & Available for Installation	4QFY16
2	Coax Line/ Waveguide Rec'd & Available for Installation	4QFY16
2	Circulators and DL Rec'd & Avail for Installation	4QFY16
2	2.1 GHz Warm Cavity Available for Installation	1QFY17
2	704 MHz Warm Cavity Available for Installation	1QFY17
2	Transport Solenoids Characterized & Available for Installation	1QFY17
2	704 MHz Warm Cavity & Stand Installation Complete	1QFY17
2	704 MHz Warm Cavity Tuner Installation Complete	1QFY17
2	SRF Gun (704MHz Booster Cavity) Removal Start	2QFY17
2	ERL Testing Complete Laser is Available for LEReC Installation	2QFY17
2	Power Supplies for the Matching Solenoids Received & Available for Installation	2QFY17
2	2.1 GHz 3rd Harmonic System Install Complete	2QFY17
2	SRF Gun Characterization Complete	2QFY17
2	Instrumentation Controls Installation Complete	3QFY17
2	SRF Gun (704MHz Booster Cavity) Available for Installation	4QFY17
2	Metal Shielding Received and Available for Installation	4QFY17
2	Extraction Line Components Avail for Installation	4QFY17
2	Beam Dump Installation Complete	1QFY18
2	MU Metal Shielding Installation Complete	1QFY18
2	Install Valvebox Mod for SRF Cryostats, Gun and 5-cell Installation Complete	2QFY18
2	LEReC Commissioning Plan Submitted	2QFY18
2	ARR Final Report	3QFY18
2	SCRF Accelerator Cavities Conditioned and Ready for Beam	3QFY18
2	First Beam Test and Diagnostic with Beam Test	3QFY18
2	LEReC Sub-system installed, Tested without Beam Complete	4QFY18
2	Beam Instrumentation Tested with Beam Complete	4QFY18
2	Commissioning Finish (Deadline 9/30/2018)	1QFY19

Table 2-5 Reportable Milestones

2.4 Funding Profile

2.4.1 Planned DOE Funding

The LEReC AIP will be entirely funded by DOE-NP and the planned DOE funding profile by Fiscal Year (FY) is shown in Table 2-6.

$M				
FY14	**FY15**	**FY16**	**FY17**	**Total**
2.8	2.3	1.9	1.3	8.3

Table 2-6 LEReC Funding Profile in AY $M.

3.0 ACQUISITION APPROACH

BNL, as the prime contractor, is responsible for the design, procurement, fabrication, assembly and integration of the LEReC components. When appropriate, subcontracted equipment and material will be competitively procured through fixed-price contracts. Sole-source procurements of one-of-a-kind equipment will be supported by appropriate justification.

4.0 CHANGE CONTROL

Changes to the technical, cost and schedule baselines will be controlled using the thresholds described in Table 4-1.

All changes that include or exceed Level 2 approval thresholds should first be submitted to the Contractor Project Manager using a Baseline Change Proposal (BCP). For changes exceeding Level 2, the Contractor Project Manager will endorse the request (i.e., recommend approval) to higher authority or reject the request. If endorsed, the Contractor Project Manager will then transmit the BCP to the AIP Manager with recommendations. If the request exceeds Level 1, the AIP Manager will submit the BCP to the Federal Program Manager in DOE Headquarters for approval.

If the change is approved, the copy of the approved BCP, together with any qualifications or further analysis or documentation generated in considering the request is returned to the requestor, and copies are sent to LEReC Project Controls for implementation and filing. If approval is denied, a copy of the BCP, together with the reasons for denial, is returned to the requestor, and a copy is filed by Project Controls. The official at the next higher control level may review any granted change to ensure proper application of the procedure and consistency of the change with the goals and boundary conditions of the project.

Table 4-1 Summary of Baseline Change Control Thresholds

Level	Cost	Schedule	Technical Scope
DOE-SC-26 Program (Level 0)	A cumulative allocation of ≥ $500k contingency in WBS Level 2	3-month or more delay of a Level 1 milestone date	Change of any WBS element that could adversely affect performance specifications
C-AD AIP Manager (Level 1)	A cumulative increase of ≥ $250K in WBS Level 2 elements	> 1-month delay of a Level 1 milestone date or > 3-month delay of a Level 2 milestone date	Any deviation from technical deliverables that does not affect expected performance specifications
LEReC Contractor Project Manager (Level 2)	Any increase ≥ $50k in the WBS Level 2	> 1-month delay of a Level 2 milestone date	Technical design changes that do not impact technical deliverables

5.0 MANAGEMENT STRUCTURE

5.1 Management Structure

This section provides the management organization for the LEReC project as needed for development, fabrication, installation and testing of LEReC. Figure 5-1 outlines the LEReC management structure.

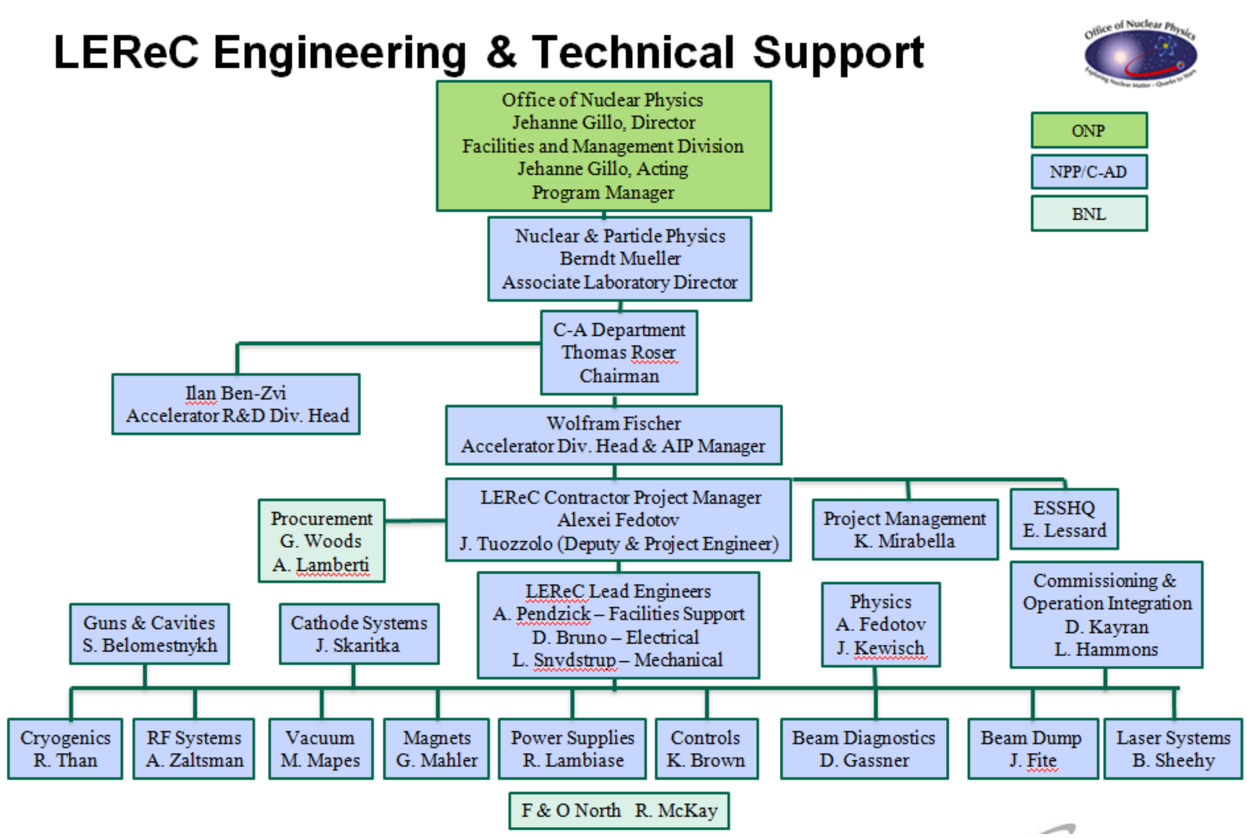


Figure 5-1: LEReC Management Organization Chart

Within the DOE Office of Science (SC), the Office of Nuclear Physics (NP) has overall responsibility for the LEReC project. The Point of Contact in the Office of Nuclear Physics is Jehanne Gillo, the Director of the Facilities and Project Management Division and acting Facilities Program Manager; she is aided by Michelle Shinn.

Director for Facilities and Project Management Division

- *Provides technical guidance to the Federal Program Manager*
- *Initiates formal periodic reviews of the project*

Facilities Program Manager in the Office of Nuclear Physics

- *Functions as DOE single point of contact for all Project matters*
- *Serves as the representative in communicating the interests of the SC program*
- *Assists with budget formulation*
- *Reviews documents and recommend approval*
- *Reviews project progress reports and deliverables*
- *Supports formal periodic reviews and tracks issues to resolution*

Brookhaven National Laboratory

- *Ultimately responsible and accountable to DOE for executing the Project within scope, cost and schedule in a safe and responsible manner.*
- *Provides access to laboratory/contractor resources, systems, and capabilities required to execute the Project.*

LEReC Contractor Project Manager (CPM)

- *Reports to the Accelerator Division Head & AIP Manager of the BNL Collider-Accelerator Department and has the responsibility and authority for delivering the project scope on schedule and within budget.*
- *Manages the execution of the project to ensure that the project is completed within approved cost, schedule and technical scope.*
- *Ensures that project activities are conducted in a safe and environmentally sound manner.*
- *Ensures ES&H responsibilities and requirements are integrated into the project.*
- *Oversees design, fabrication, installation, and construction. Represents the project in interactions with the DOE. Participates in management meetings with DOE and communicates project status and issues.*
- *Requests and coordinates internal and external peer reviews of project.*
- *Responsible for risk evaluation and management in accordance with the risk management plan.*

LEReC Deputy Contractor Project Manager (DCPM)

- *Assists the CPM in all matters relating to the LEReC Project, including the planning, procurement, disposition and accounting of resources, progress reports on project activities, ESSHQ issues, and Risk Management. In the absence of the CPM, the DCPM assumes the project management responsibilities.*
- *Ensures that effective project management systems, cost controls and milestone schedules are developed, documented and implemented to assess project performance,*
- *Responsible for overall engineering coordination of the design and fabrication phases of the project and works directly with the Level 2 Managers to achieve this.*
- *Responsible for reviewing data produced by the LEReC team to confirm it will support the LEReC key performance parameters and is consistent with its requirements.*
- *Maintains an overview of all scope requirements, including parameters, energy, power; footprints, quantities and planned locations of equipment*
- *Responsible for calling meetings as required whenever data from one area appears to be in conflict with expected outcomes and/or project scope and direction.*

LEReC Subsystem Managers

- *Responsible for the design, fabrication, assembly, and testing of their subsystem in accordance with the performance requirements.*

- *Provide a monthly status on both technical progress and schedule.*

LEReC Project Management

- *The C-AD Project Management personnel assist the project staff in developing the required documentation, reports, project plan, and enable control of the cost and schedule.*

LEReC ESSHQ

- *The ESSHQ lead is responsible for ESSHQ coordination between the LEReC project and the ESSHQ organization at BNL and other participating institutions.*

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6.0 PROJECT MANAGEMENT/OVERSIGHT

6.1 Risk Management

Risk management is based on a graded approach in which levels of risk are assessed for project activities and elements and assessments of technical, cost and schedule risks are conducted throughout the project lifecycle. The Risk List is provided as Appendix B.

The LEReC risk management approach consists of a five-step process:

1. Identifying potential project risk – any member of LEReC may suggest a potential risk. The subproject (WBS level 2) managers are responsible for addressing the potential risk with the DCPM or CPM concurrence.

2. Analyzing project risk - the probability of the risk occurring together with the potential impact to the project's technical performance, cost and/or schedule baseline. Probability is assessed qualitatively (Low, Moderate, and High).

3. Planning risk abatement strategies.

4. Executing risk abatement strategies - abatement strategies differ according to the potential risk and its timing. A table of abatement strategies is included in the Risk Management plan.

5. Monitoring and tracking the results and revising risk abatement strategies - risk assignments are associated to specific WBS entries down to Level 3. The WBS number will also serve as the Risk Index. This serves to emphasize the role of the Level 2 WBS manager in risk management. Risk information, including the probability and impact assessments and brief summaries of mitigation strategies, are stored in the LEReC document repository.

In addition to the task-based risks at the sub-system level there are broader risks to the project to be considered:

- Delays in funding, e.g., due to an extended continuing resolution:
  The LEReC project plan assumes funding for each new FY arrives at the beginning of 2QFY in that year. Any additional delays may result in schedule disruptions due to, e.g., procurement delays or reassignments of planned-for engineering/technician effort.
- RHIC run schedule and off-project contributions:
  The RHIC schedule for shutdown periods constrains periods where in-tunnel installation can take place.

6.2 Project Reporting and Communication

The CPM participates in monthly AIP teleconference calls with the DOE Office of Nuclear Physics. It is anticipated that ONP will have progress reviews as required.

The standard BNL accounting system is the basis for collecting cost data, and the Control Account structure for LEReC will separate costs according at pre-defined WBS levels.

Technical performance is monitored throughout the project to insure conformance to approved functional requirements. Design reviews and performance testing of the completed systems are used to ensure that the equipment meets the functional requirements.

6.3 Earned Value Management System (EVMS)

Brookhaven National Laboratory has a certified EVMS that complies with the ANSI/EIA-748 Standard. The LEReC TPC is below the threshold for requiring EVMS Reporting. The health of the project will be assessed using milestone status, weekly/monthly teleconferences, and face-to-face meetings as necessary.

6.4 Project Reviews

Independent Reviews of the AIP's status and management may be conducted as needed.

6.5 Engineering and Technology Readiness

The project will assess engineering and technology readiness through design reviews, IPRs, and other independent technical reviews as required.

6.6 Environment, Safety and Health

6.6.1 Integrated Safety Management

The Integrated Safety Management (ISM) policy for this project requires full commitment to safety by the project management team. Principles of ISM are incorporated into project planning and execution, following the guidelines described in the BNL Standards Based Management System (SBMS). All phases of the project will be carried out in compliance with ES&H policies and procedures, and the LEReC CPM will work collaboratively to help ensure work is being performed in an appropriately safe manner.

6.6.2 Environmental and Regulatory Compliance

It was expected that there would be no significant environmental, regulatory or political sensitivities that impact the project, and appropriate National Environmental Policy Act (NEPA), State, and local requirements have been addressed and completed. In September 2013 the NEPA Compliance Officer at BHSO determined that LEReC would be categorically excluded from further NEPA review.

6.6.3 Review of ESSH Issues Associated with Project Design

At the design stage, C-AD personnel plan, develop, define and control the design of the C-A facilities and its components in a manner that assures consistent achievement of safety, environmental protection and mission objectives. To assist in determining the necessary ESH reviews for a project, each Project Manager/Project Physicist/Project Engineer must complete a C-AD Design Review Questionnaire. The questionnaire identifies required documents, approvals, calculations, drawings, materials certifications, variances and procedures need to complete the project. The questionnaire also identifies any required safety reviews by standing C-AD or BNL ESH review committees.

For example, the Collider-Accelerator Department's Radiation Safety Committee will review facility-shielding configuration designs (if applicable) to assure that the shielding has been designed to:

- Prevent contamination of the ground water.
- Limit annual site-boundary dose equivalent to less than 5 mrem.
- Limit annual on-site dose equivalent to inadvertently exposed people in non-Collider-Accelerator Department facilities to less than 25 mrem.
- Limit dose equivalent to any area where access is not controlled to less than 20 mrem during a fault event.
- Limit the dose equivalent rate to radiation-workers in continuously occupied locations to ALARA but in no case greater than 0.5 mrem in one hour or 20 mrem in one week.
- Limit the annual dose equivalent to radiation workers where occupancy is not continuous to ALARA, but in no case to exceed 1000 mrem.

In addition to review and approval by the Radiation Safety Committee, the Radiation Safety Committee Chair or the ESSHQ Associate Chair must approve final shielding drawings. Shielding drawings are verified by comparing the drawings to the actual configuration. Radiation surveys and fault studies are conducted after the shielding has been constructed in order to verify the adequacy of the shielding configuration. The fault study methodology that is used to verify the adequacy of shielding is described and controlled by Collider-Accelerator Department procedures.

The DOE ESSHQ requirements applicable to Projects at C-AD's accelerator facilities are listed in Table 6-1. All non-standard industrial hazards, including radiological hazards, associated with accelerator facilities are addressed comprehensively in DOE Order 420.2C, Safety of Accelerator Facilities. Appropriate and adequate protection of workers, the public, and the environment from ionizing radiation are also covered under 10CFR835, Occupational Radiation Protection, which applies to all DOE facilities regardless of the source and type of ionizing radiation. Protection against routine industrial hazards is covered in 10CFR851, Worker Safety and Health Program. The C-A Department implements the DOE requirements indicated in Table 6-1 using procedures and training. At the BNL level, the Standards Based Management System (SBMS) is used to keep DOE requirements current and to flow requirements down to the Department level. At the C-A Department level, SBMS requirements are flowed down into routine operations procedures. All ESSHQ requirements and hazard controls are documented in detail in the C-A Operational Procedures (OPM).

In order to meet the requirements in DOE Order 420.2C, Safety of Accelerator Facilities, C-AD incorporates a description and safety assessment of new equipment into the current Safety Assessment Document (SAD) for C-AD. At the appropriate time, the C-A Department obtains an approved Accelerator Safety Envelope for new equipment from DOE and performs an Accelerator Readiness Review in accord with Order 420.2C prior to commissioning and operations.

Table 6-1 Significant DOE ESSHQ Requirements for BNL Accelerators

Topic	DOE Requirements Document
Authorization Basis Documents	DOE O 420.2C, Safety of Accelerator Facilities DOE O 420.1C, Facility Safety (Natural Phenomenon and Fire Protection Sections)
Conduct of Operations	DOE O 422.1, Conduct of Operations Requirements for DOE Facilities
Quality Assurance	DOE O 414.1D, Quality Assurance
Maintenance Management	DOE O 430.1B, Ch. 2, Real Property Asset Management
Training and Qualification Programs	DOE O 420.2C, Safety of Accelerator Facilities
Radiation Protection	10CFR835, Occupational Radiation Protection
Transportation and Packaging	DOE O 460.2A, Departmental Materials Transportation and Packaging Management
Worker Protection	DOE O 450.2, Integrated Safety Management 10CFR851, Worker Safety and Health Program
Environmental Protection	DOE O 451.1B Chg 3, National Environmental Policy Act Compliance Program - Change 1
ESH Reporting	DOE O 231.1B, Environment, Safety, and Health Reporting
Accident Investigation	DOE O 225.1B, Accident Investigations
Radioactive Waste Management	DOE O 435.1 Chg 1, Radioactive Waste Management

The C-A Department also conforms to the requirements of ISO 14001, Environmental Management System, and OHSAS 18001, Occupational Safety and Health Management System, and achieves third-party registration for these internationally recognized management systems.

Thus, in addition to DOE requirements, documentation of environmental protection and occupational safety and health programs for new facilities and projects are prepared and audited by independent parties. This documentation includes:

- Environmental Process Evaluations for all processes with significant environmental aspects
- Facility Risk Assessments for all facilities and areas
- Job Risk Assessments for all jobs

DOE O 420.1A, Facility Safety, has two sections that are applicable to accelerator facilities: Natural Phenomenon and Fire Protection Sections. DOE STD-1020-2002, Natural Phenomena Hazards Design and Evaluation Criteria for Department of Energy Facilities, describes the Performance Criteria (PC) to be used for evaluating building design for earthquake, wind and flood phenomena. DOE-STD-1020-2002 employs the graded approach in assigning PC categories to DOE buildings. The graded approach enables cost-benefit studies to be used to address categorization. BNL is currently using PC1 for all existing C-AD facilities for life safety issues; however, all projects are reviewed and categorized according to their own unique details.

Significant environmental aspects of new equipment could include:

- Excavation
- Chemical Storage/Use
- Liquid Effluent
- Airborne Effluents
- Hazardous Waste
- Radioactive Waste
- Radiation Exposures
- New or Modified Federal/State Permits

If cooling water is used, the existing New York State Pollutant Discharge Elimination System (SPDES) permit would be revised, as necessary, based on the disposition of cooling tower discharge. Discharge of contaminants to the ground or to the sanitary system would be neither planned nor expected. The closed loop cooling system would be connected to the cooling tower via a heat exchanger. Cooling-tower water would be treated either with ozone or with biocides and rust inhibitors, and would meet all SPDES effluent limits.

If airborne emissions result from facilities or projects, then the National Emission Standards for Hazardous Air Pollutants (NESHAPS) is implemented. Examples of sources that are identified and assessed include point sources such as stacks, diffuse sources such as activated air from accelerator enclosures, and bench-top work conducted in ventilation hoods.

6.6.4 ESSHQ Plans for Construction

All requests for goods or services are processed through a formal and well-documented system of review to incorporate any special ESSHQ requirements of the contractor or vendor. BNL reviews the proposed contract scope of work using the Work Planning and Control for Experiments and Operations Subject Area (Work Planning & Control). Building modification and utility drawings for new equipment are sent to the BNL's Safety and Health Services Division for review by the appropriate Environment, Safety and Health (ES&H) disciplines.

C-AD defines the scope of work for each project with sufficient detail to provide reviewers and support personnel with a clear understanding of what is needed, expected, and required. This includes the type of work to be performed, location of work, defined contract limits, allowed access routes, and any sensitive or vulnerable laboratory operations or infrastructure that may be impacted by this work. The C-AD ensures that facility hazards are characterized and controls implemented specific to the expected construction location and activities.

BNL and C-AD ensure that minimum ESSHQ competency requirements for contractors are detailed and provided to the Procurement & Property Management Division (PPM). PPM includes those requirements in the bid and contract documents to qualify contractors for award. Competency requirements are consistent with the project, facility and job to be performed.

6.6.5 ESSHQ Plans for Commissioning, Operations and Decommissioning

The C-AD identifies hazards and associated on-site and off-site impacts to workers, the public and the environment from the C-AD accelerator facilities and projects for both normal operations and credible accidents. Sufficient detail is provided in a C-AD Safety Assessment Document (SAD) to ensure that C-AD has performed a comprehensive hazard and risk analysis. The amount of descriptive material and analysis in the SAD relates to both the complexity of the facility and the nature and magnitude of the hazards. In addition, the SAD provides an understanding of radiation risks to the workers, the public and the environment.

The C-AD SAD follows the generally accepted principles identified in DOE Order 420.2C. Prior to commissioning, or operations, an independent Accelerator Readiness Review is performed for accelerators. C-AD uses procedures and training for commissioning and operations according to requirements in DOE O 422.1, Conduct of Operations Requirements for DOE Facilities. For projects that are not accelerators, a BNL Operational Readiness Evaluation is performed. All equipment and systems created/upgraded by a Small Project are the subject of a separate and distinct Hazard Analysis at the onset of the project. For projects that have non-standard industrial hazards, a safety analysis is performed and credited controls or engineered safety systems are defined and configuration controlled.

Post-operations activities would include a transition period, deactivation, decommissioning and remedial surveillance and maintenance activities. These activities will require development of a written plan that meets whatever requirements are in place at the time of post-operations. For large projects, the expectation for a post-operations plan would be that it follows the principles of DOE O 430.1B, Ch. 2, Life Cycle Safety Asset Management.

6.7 Project Quality Assurance Program

6.7.1 Program

The project, through the Collider-Accelerator (C-A) Department, shall adopt in its entirety the BNL Quality Assurance (QA) Program. This QA Program describes how the various BNL management system processes and functions provide a management approach, which conforms to the basic requirements defined in DOE Order 414.1D, Quality Assurance.

The quality program embodies the concept of the "graded approach" i.e., the selection and application of appropriate technical and administrative controls to work activities, equipment and items commensurate with the associated environment, safety and health risks and programmatic impact. The graded approach does not allow internal or external requirements to be ignored or waived, but does allow the degree of controls, verification, and documentation to be varied in meeting requirements based on environment, safety and health risks and programmatic issues.

The BNL QA Program would be implemented within the projects using C-A QA implementing procedures. These procedures supplement the BNL Standards Based Management System documents for those QA processes that are unique to the C-A Department. C-A QA procedures are developed by C-A QA and maintained in the C-A Operations Procedures Manual (Chapter 13: ESSHQ Division).

The C-A QA philosophy of adopting the BNL Quality Program and developing departmental procedures for the implementation of quality processes within C-A ensures that complying with requirements will be an integral part of the design, procurement, fabrication, construction and operational phases of the projects.

A Quality Representative has been assigned to serve as a focal point to assist C-A management in implementing QA program requirements. The Quality Representative has the authority, unlimited access, both organizational and facility, as personnel safety and training allows, and the organizational freedom to: assist line managers in identifying potential and actual problems that could degrade the quality of a process/item or work performance, recommend corrective actions, and verify implementation of approved solutions. All C-A personnel have access to the Quality Representative for consultation and guidance in matters related to quality.

6.7.2 Personnel Training and Qualifications

The BNL Training and Qualification Management System (Training and Qualifications) within the Standards Based Management System supports C-A management's efforts to ensure that personnel working on the projects are trained and qualified to carry out their assigned responsibilities. The BNL Training and Qualification Management System (Training and Qualifications) is implemented within the C-A Department with the C-A Training and Qualifications Plan of Agreement (Training Plan).

6.7.3 Documents and Records

The BNL Records Management System (Records Management) and controlled document Subject Areas within SBMS, supplemented by C-A procedures, provide the requirements and guidance for the development, review, approval, control and maintenance of documents and records.

C-A documents encompass technical information or instructions that address important work tasks, and describe complex or hazardous operations. They include plans, and procedures, instructions, drawings, specifications, standards and reports.

6.7.4 Work Process

Work is performed employing processes deployed through the BNL SBMS. SBMS Subject Areas are used to implement BNL-wide practices for work performed. Subject Areas are developed in a manner that provides sufficient operating instructions for most activities. However, C-A management has determined that it is appropriate to develop internal procedures to supplement the SBMS Subject Areas. These C-A procedures are bounded by the requirements established by the BNL Subject Areas.

Group leaders and technical supervisors are responsible for ensuring that employees under their supervision have appropriate job knowledge, skills, equipment and resources necessary to accomplish their tasks. Where applicable, contractors and vendors are held to the same practices.

6.7.5 Design

Design planning shall establish the milestones at which design criteria, standards, specifications, drawings and other design documents will be prepared, reviewed, approved and released. The design criteria shall define the performance objectives, operating conditions, and requirements for safety, reliability, maintainability and availability, as well as the requirements for materials, fabrication, construction, and testing. Appropriate codes, standards and practices for materials, fabrication, construction, testing, and processes shall be defined in the design documentation. Where feasible, nationally recognized codes, standards and practices shall be used. When those are either overly restrictive, or fall short of defining the requirements, they shall be modified, supplemented, or replaced by BNL specifications.

Specifications, drawings and other design documents present verifiable engineering delineations in pictorial and/or descriptive language representations of parts, components or assemblies for the project. These documents shall be prepared, reviewed, approved and released in accordance with C-A procedures. Changes to these documents shall be processed in accordance with the C-A configuration management program.

6.7.6 Procurement

Personnel responsible for the design or performance of items or services to be purchased shall ensure that the procurement requirements of the purchase request are clear and complete. Using the graded approach, potential suppliers of critical, complex, or costly items or services shall be evaluated in accordance with predetermined criteria to ascertain that they have the capability to provide items or services which conform to the technical and quality requirements of the procurement. The evaluation shall include a review of the supplier's history with BNL or other DOE facilities, or a pre-award survey of the supplier's facility. C-A personnel shall ensure that the goods or services provided by the suppliers are acceptable for intended use.

6.7.7 Inspection and Acceptance Testing

The BNL Quality Management System within the SBMS, supplemented by C-A procedures, provides processes for the inspection and acceptance testing of an item, service or process against established criteria and provides a means of determining acceptability. Based on the graded approach, the need and/or degree of inspection and acceptance testing shall be determined during the activity/item design stage. Inspection/test planning has as an objective the prompt detection of non-conformances that could adversely affect performance, safety, reliability, schedule or cost.

6.7.8 ESSHQ Plans for Fabrication

The LEReC project will use the BNL SBMS to identify and control hazards for all equipment and work at BNL for LEReC. C-AD has review processes that comply with the BNL SBMS. The project will prepare designs and work procedures and have them reviewed by the appropriate laboratory or department review committees. The equipment and work practices will be reviewed by the C-AD Experimental Safety Review Committee (ESRC). The reviews of the ESRC are covered in C-AD Operations Procedures Manual (OPM) Chapter 9 Section 2. The installation will be covered under the rules and safeguards in place for work in the RHIC tunnel.

The risk analysis in the Hazard Analysis Document (HAD) addresses the hazards of LEReC. It also addresses hazards, controls and risks for experimental halls, experiments and their associated targets and detectors. The Safety Assessment Document (SAD) follows the generally accepted principles identified in DOE Order 420.2C.

6.7.9 DOE ESSHQ Oversight

The CPM has the overall responsibility for the ESSHQ implementation to ensure that the project is constructed safely. He will maintain cognizance of all project activities, including the final ESSHQ plan and subsequent updates. The CPM is assisted in these responsibilities by the DOE Facility Representative from BHSO. The Operations Management Division at BHSO will coordinate ESSHQ oversight with the DOE Facility Representative. The DOE Facility Representative will coordinate with other subject matter experts (e.g., health physics) in the Operations Management Division as needed. BHSO personnel will monitor the LEReC fabrication activities on a regular basis to ensure that planned BNL oversight is being performed and that applicable BNL plans are being followed.

At BNL, BNL management is responsible for ensuring the safety (including meeting all requirements) of the project. BHSO oversight is planned to monitor BNL's activities and to assess BNL's systems for ensuring safety and environmental compliance. This will include review of the various plans and procedures developed by BNL, and field operation awareness activities to ensure that BNL oversight is functioning properly. Applicable ESSHQ disciplines, such as construction safety, industrial hygiene, and waste management, will be identified for the project. Oversight activities under each applicable discipline will be performed as needed to monitor BNL performance.

6.8 Value Engineering

As part of the Peer Review process, the design and fabrication is being reviewed and evaluated with Value Engineering principles in mind. Project personnel continue to evaluate alternative design approaches and the flexibility of the design for present and future research as appropriate. The VE approach will determine the impacts on cost (both project and life cycle) of any suggested changes to the design.

6.9 Transition to Operations

Before Project completion a transition to operations plan will be developed. Guidance for the operation planning will be provided by the DOE Office of Nuclear Physics.

6.10 Project Closeout

Project closeout will begin when all equipment has been installed and subsystem measurements to verify the KPPs have begun. A Draft Closeout report will be developed prior to Project completion and is expected to address demonstration of KPPs, Lessons Learned, the closure status of purchase orders, the expected total cost of the Project and when the Project is expected to close the control accounts and complete the financial closeout.

7.0 GLOSSARY

AIP	Accelerator Improvement Project
AY	At-Year
BHSO	Brookhaven Site Office
BNL	Brookhaven National Laboratory
BRAHMS	Broad Range Hadron Spectrometers Experiment
BSA	Brookhaven Science Associates
C-AD	Collider Accelerator Department (at BNL)
CeC	Coherent electron Cooling
CPM	Contractor Project Manager
DOE	Department of Energy
DCPM	Deputy Contractor Project Manager
ES&H	Environmental, Safety and Health
ERL	Energy Recovery Linac
ESRC	Experimental Safety Review Committee
ESSHQ	Environmental, Safety, Security, Health, and Quality
EVMS	Earned Value Management System
FTE	Full Time equivalent
FY	Fiscal Year
HAD	Hazard Assessment Document
HTS	High Temperature Superconductor
IP	Interaction Point
IR	Interaction Region
ISM	Integrated Safety Management
KPP	Key Performance Parameter
LEReC	Low Energy RHIC electron Cooling
NEPA	National Environmental Policy Act
NP	Nuclear Physics
OPM	Operational Procedures Manual
PARS	Project Assessment and Reporting System
PEP	Project Execution Plan
PoP	Proof of Principle
QA	Quality Assurance
QCD	Quantum Chromo Dynamics
QGP	Quark Gluon Plasma
R&D	Research & Development
RHIC	Relativistic Heavy Ion Collider
SAD	Safety Assessment Document
SBMS	Standards Based Management System
SC	Office of Science
SOW	Statement of Work
SRF	Superconducting Radio Frequency
TPC	Total Project Cost
UPP	Ultimate Performance Parameters
WBS	Work Breakdown Structure

APPENDIX A WBS DICTIONARY

This dictionary gives a succinct definition of some of the most important tasks included in the WBS.

1.1 Project Management

Level of effort tasks associated with the daily management, oversight, and assessment of the project. The effort includes the labor of the Contractor Project Manager, Project Controls, ESSHQ, financial oversight, documentation and reporting.

1.2 Physics Support

This WBS element covers accelerator physics support during execution of the project for evaluation of systems requirements and value engineering. The accelerator physics group works with the systems engineering teams to ensure that the design and construction will support achievement of the physics goals of the project. Major tasks include optimization of electron beam parameters and electron beam dynamics for various energies of operation; development of electron beam transport machine optics, physics requirements and specifications for all the hardware elements and commissioning of the SRF accelerator in Bldg. 912, including evaluations of needed repairs and modifications to ensure that the SRF gun is capable of delivering performance needed for the project.

1.3 Gun & Cavities

SRF electron gun
The SRF electron gun is the gun originally designed for the R&D ERL to generate very high beam currents. For use in LEReC, it will require modification of RF coupling. This will be accomplished by using external three-stub waveguide tuners. An HTS solenoid will require modification of the current leads for CW operation. The gun is presently under commissioning with beam and is yet to achieve beam parameters and stable operation required for LEReC.

DC electron gun
The DC photoemission gun which was developed at Cornell University achieved electron beam parameters which are needed for LEReC project. Under the contract with BNL, Cornell will build similar DC gun for the LEReC project with funding outside LEReC funding profile.

Warm Cavities
The 2.1 GHz warm RF cavity is required to correct beam energy spread after the SRF gun. This will be a multi-cell standing wave structure with water-cooling and a CEBAF-style waveguide RF window. The cavity will be designed at BNL and procured from industry.

The 704 MHz warm RF cavity to correct energy spread of stretched electron bunches. This will be a single cell cavity with design similar to the 714 MHz developed at LBNL for the NLC damping ring.

The 9 MHz warm RF cavity for correction of bunch-to-bunch energy variation inside the 30 bunch trains. This variation is due to beam loading effect in other cavities. This is already existing RHIC 9 MHz bouncer cavity system.

1.4 RF Amplifiers and LLRF

This WBS covers design, specification, purchasing and testing of all high power components, as well as moving and retuning existing equipment that is currently used by ERL and CeC for driving RF cavities. It also covers design, production of the LLRF and its synchronization to RHIC.

1.5 Magnets

The magnets required are a variety of warm bore quadrupoles, dipoles, solenoids, and multifunction magnetic assemblies. These magnets are to be fitted in an assortment of transfer line installations.

The bulk of the warm quadrupoles consists of 26 assemblies that will be repurposed from the existing Energy Recovery Linac installation. These are air cooled magnet assemblies built by Everson Tesla Corporation. There is a second quadupole assembly that will be designed and manufactured which is to be installed nearest the Q4 turnaround and at the entrance of the dump. The majority of dipole magnets required are of similar design to the existing warm bore dipoles used on the Coherent Electron Cooling project, but the design will be modified in accordance with the requirements of this project. These new assemblies will be redesigned and purchased. The remaining dipoles will be repurposed from the Energy Recovery Linac project. These dipoles will be repurposed by shimming the existing assemblies. The Q4 turnaround requires two warm bore dipoles of new design. The multifunction dipoles required will be repurposed from the ERL project. Warm bore solenoid assemblies are required in the two cooling sections, which are of new design. Stands and an assortment of installation components will be of original design and procurement.

1.6 Power Supplies

The scope of this WBS includes the purchase of commercial, off the shelf power supplies for a large quadrupole, large aperture solenoids and correctors; as well as the repurposing of quantities of those power supplies as well as supplies for the Bend magnet, small quadrupoles, dipole trims and high temperature superconducting solenoids. Also included is modification of an existing Quench Detection System.

1.7 Beam Instrumentation

<u>Beam Profile Monitors</u>
Transverse beam profiles are measured by plunging a thin YAG:Ce crystal into the electron beam path, a local CCD camera acquires the image produced by the interaction. Image processing software can provide beam size sigma, centroid, Gaussian fits and Chi-squared fitting accuracy. A pepper pot station will be used to measure horizontal and vertical emittance.

Beam Current Monitors
A commercially available assembly that consists of a ferrite toroid wound with many turns of signal wire is positioned around a ceramic break in the beam transport, all enclosed in a protective shroud. This is used as a non-destructive technique to measure the beam current or bunch charge depending on the style of detector installed. A separate set of wire turns on the DCCT toroid is used for injecting a calibration signal. Matching commercial signal processing electronics are included for each detector to provide data to operations.

Beam Loss Monitors
Photomultiplier style and ion chamber style beam loss detectors distributed throughout the transport and mounted near the beam pipe will be used to measure radiation caused by lost beam particles. Associated signal processing electronics will be provided for each detector.

Beam Position Monitors
Dual plane BPM button style pick-ups will be distributed at select locations throughout the beam transport. The signal from each button is delivered to the signal processing electronics using heliax cables. The signal processing electronics will be a new BNL design that is in a VME module.

Beam Halo Monitor
An isolated copper jaw that can be plunged into the electron beam path using precise stepper motor controls will be used to intercept the electrons in the halo of the beam. The amount of halo intercepted is related to the transverse beam characteristics and the plunge depth. In order to measure the amount of intercepted electrons, we will attempt to measure the signal directly from the isolated jaw, compare measurements from a downstream Faraday Cup or current monitor, or observe beam loss signals from a nearby PMT beam loss monitor.

Recombination Monitor
In order to measure the number of ions that have accumulated electrons while co-propagating with the electron bunch during the cooling process, a detector will be located near the place where simulations determine where these ions with a non-ideal charge state will be lost. This is most likely near the RHIC collimators. The detector planned is a scintillator coupled to a photomultiplier tube and signal processing electronics (counting) that can provide scalar data that can be logged versus time.

RF cavity Tuners Motion Control
Stepper motors will be used to control the position of the RF cavity tuners. The motors will be connected via long cables to commercially available stepper drivers that will communicate to VME motion control modules. Position transducers will provide continuous measurement of the tuner actuator position.

1.8 Beam Dump

After cooling ions in the Blue and Yellow rings the electron beam is transported to the beam dump. The beam dump must be suitable for 2.0 MeV, 50 mA, and a power dissipation of 100 kW maximum. The BNL ERL beam dump, rated for 5 MeV, 500mA, 1 megawatt will be transferred for use in the LEReC beam line after being used in the ERL beam line. Magnets upstream of the dump will be designed to evenly distribute the electron beam on the inner dump surfaces to lower thermal stress and to minimize local heat flux into the cooling water. The ERL dump assembly includes beam loss monitors and steel shielding.

1.9 Beam Line Vacuum

<u>Beam pipes/Chambers</u>
Pipes or chambers that have vacuum pressure inside and provide a path for the ion to be transported, as well as provide a housing for special components inside the vacuum system.

<u>Vacuum Instrumentation & Control</u>
A PLC-based control system used to monitor and control the vacuum system and components such as gauges, pumps and valves.

<u>Vacuum Pumps</u>
Pumps used to evacuate or pump down a vacuum chamber from atmospheric pressure to the desired high vacuum or ultra-high vacuum range.

<u>Vacuum Valves</u>
Manual or pneumatically operated valves used to isolate vacuum pumps and/or a section of the beam line from another section or vacuum chamber.

1.10 Controls

LEReC controls will consist of standard networked, front-end interfaces connected via Ethernet to central C-AD servers and console workstations. Custom application software will be provided as needed, but extensive re-use will be made of existing software designs with LEReC database additions.

Interfaces to all equipment will be managed through standard C-AD controls interfaces, either via distributed VME based computing systems composed of both custom designed and commercial VME modules, or through direct Ethernet or other standard interfaces (i.e., GPIB, RS232, etc.). Interfaces will include networking infrastructure, timing links, machine protection, power supply controls, instrumentation interfaces, vacuum system interfaces, laser system interfaces, and environmental monitoring. Standard interfaces for RF and Cryogenics systems will be built, but the respective groups handle most of the controls for these systems.

LEReC will be constructed inside the existing RHIC tunnel. Facility access controls and radiation interlocks will provide personnel protection in the LEReC areas.

Some custom software in the form of device drivers, interfaces software, and applications will be built for the LEReC project. This is to provide a comprehensive user interface for controlling most of the LEReC systems. Data acquired through the Controls interfaces are processed, displayed, and archived through a system of servers and workstations that are supported by the Controls groups.

1.11 Cryogenic Systems

Level of effort associated with overall design, system engineering and process flow diagrams and process specifications of system and components, layout, technical reviews, and safety reviews. System level definition of controls system hardware and architecture requirements for the project.

Triplet M-Line Tap
Level of effort associated with engineering, design drawings, procurement of parts, and installation/modification of a tap into the main liquid helium line of the RHIC cryogenic distribution system. Consists of opening up a RHIC Triplet magnet cryostat vacuum boundary and tapping into the main liquid helium line. Includes cryogenic valve and vacuum jacketed bayonet.

4.5K VJ line to Cryostat valvebox(es)
Level of effort and cost associated with engineering, design drawings, procurement, and installation of the cryogenic supply transfer line from the Triplet M-line tap to the cryostats' valveboxes.

Valvebox(es) Mods for SRF Cryostats Gun and 5-cell
The existing ERL valveboxes that accompany the 704MHZ cryostats, will be re-used but modifications to the ERL valveboxes to include phase separators with subcooler coils and associated valve and instrumentation is required to improve top fill efficiency to the 2K bath, and to provide 3 atm supercritical helium to the cathode cooling loop on SRF Gun cryostat, and to the beam tube intercepts at the 5-cell cryostat.

100 ft 2"x4 VJ Return 20Torr Lines to CeC Return Heaters
To produce 2K at the cavity cryostats existing subatmospheric pumps from the CeC project will be used. A vacuum jacketed return line to return the low pressure helium gas from the cavities to existing 20 Torr warmup heaters and onto the existing 2K pumping system.

VJ flex lines cathode stalk cooling loop
For cooling the cold cathode with supercritical helium a new set of flexible connecting transfer lines with cryogenic bayonets, and isolation valves is required to interface to the helium system. This is to supply and return 3.8 bar supercritical helium to the cathode.

LN2 Cooling System for Cathode
Since there is no existing LN2 at the 1002 Collider location, and new liquid nitrogen storage system and distribution system is required. A recirculating pumped subcooled liquid nitrogen cooling loop option will be studied as an alternate option for the current once through system design since the predicted heat dissipation for the new cold cathode design is more than doubled that of the original design basis.

100 ft 4.5K VJ Return line to R/U header
Cryogenic transfer line returning 1.2 atm cold vapor to RHIC's main cryogenics system's R header, continuously from the phase separators and from the SRF cavities during 4.5K mode.

R/U tap

Tap into the main cold vapor return helium line of the RHIC cryogenic distribution system. Consists of opening up a RHIC vacuum jacket bundle field joint and tapping into the R (Return) header line. Includes cryogenic isolation valve and vacuum jacketed bayonet.

1.11 Installation

Civil construction includes all the necessary power & tray, water cooling, compressed air, & infrastructure improvements needed to support this Project. The cost estimates take full advantage of the existing utilities presently available in IP2.

While installation labor is included in the individual system estimates, installation coordination, Trades support, & general survey are provided

1.12 Commissioning

Level of effort starting with the commissioning of the SRF accelerator (704 MHz SRF gun and 704 MHz 5-cell cavity) in Bldg. 912. Construction and commissioning of the DC photoemission gun as an alternative to the SRF gun. Achieving parameters specified by the KPPs from the SRF accelerator in Bldg. 912. Evaluation and oversight of needed modifications to ensure that either of the guns can deliver performance needed for the project.

Full system integration in RHIC tunnel. This includes full installation of electron beam transport starting with the electron gun and all the way to the beam dump. Commissioning of each installed system with the beam and finally beam tuning of an entire electron beam transport from the gun to the dump. Activities will include the measurements of beam currents, profiles, emittances, verification of beam energy and energy spread. Commissioning ends when the performance required for the KPPs has been demonstrated.

APPENDIX B RISK LIST

	WBS	Risk Description	Type of Risk	Consequence	Likeli-hood	Schedule Consequence	Cost Impact (burdened $k)	Risk Expiration	Mitigation Plan
High Risk	1.0	Electron gun must demonstrate 50 mA CW operation with beam parameters (bunch charge and emittance) needed for cooling	Technical	Level 1	U		0	4QFY18	Cornell University will construct DC gun (funded off-project) similar to the gun which already demonstrated needed parameters. SRF gun in R&D ERL is under commissioning.
	1.0	Production delivery date delays by vendors on multiple components for magnets, power supplies, RF equipment, cryogenics, instrumentation, etc.	Schedule	Level 2	VL	12 weeks	0	2QFY18	BNL purchasing division has assigned a single point of contact for all LEReC procurement who will work with engineering staff on procurement and oversee vendor performance to schedule. The schedule consequence does not impact Project completion.
Medium Risk	1.0	Cryogenic systems, magnet systems, and RF systems will require design and engineering support from 3QFY14 through 2QFY18 for detailed modeling, design, and installation drawings needed for equipment specific to this project.	Schedule	Level 2	L	4 weeks	---	2QFY18	Use of overtime in the design room, limiting additional new projects during LEReC design, realigning project priorities, and hiring staff if needed. The schedule consequence does not impact Project completion.
	1.5	Magnets require correctors as a result of beam dynamics tolerances studies and magnet field measurements	Cost, Schedule, Technical	Level 2	L	16 weeks	100	4QFY17	Tolerance studies will be done with detailed simulations. All magnets will be measured and correctors added as needed. The schedule consequence does not impact Project completion.
Low Risk	1.7	Absolute energy measurement of electron beam requires building dedicated spectrometer beam line	Cost	Level 3	L		200	2QFY16	Various methods are being evaluated.
	1.3	SRF Gun Cathode lifetime, as determined by ERL testing, is lower than design specification.	Technical	Level 2	U		---	1QFY17	Redesign of the cathode insertion system has been added to the ERL R&D program to allow the loading and remote changing of multiple cathodes for efficient egun operations. The cathode production system is also being upgraded to increase production rate.
	1.0	RHIC operating schedule/priorities cause installation delay	Schedule	Level 2	U	4 weeks	---	3QFY17	Careful installation planning, install early, work 2 shifts, coordinate with C-AD Ops. The schedule consequence does not impact Project completion.
	1.0	The LEReC return beam lines adjacent to the triplet in the 01:00 section of RHIC will make access to the LEReC equipment difficult.	Technical	Level 3	L		---	3QFY17	The cable tray, water lines, air lines, magnet, instrumentation, and vacuum stands need to be carefully designed to provide access to the equipment and to meet safety rules for egress.
	1.0	Incoming inspection and testing delays for new components for magnets, power supplies, RF equipment, cryogenic, instrumentation, etc.	Schedule	Level 2	U	8 weeks	---	2QFY18	Maintain staffing levels and funding to support operations, testing of new equipment, and installation. Use of overtime where necessary. The schedule consequence does not impact Project completion.
	1.6	Power supply tolerances (stability) outside of specifications	Technical	Level 3	U		---	3QFY17	Frequent communication with manufacturer, testing and verification upon delivery
	1.5	Failure of upstream magnet(s) designed for over-focusing/spreading of the beam will impact the dump and could possibly burn a hole in the dump itself	Technical	Level 2	U		0	4QFY18	Testing of existing ERL will provide experience in beam control and insight into energy dissipation into the beam dump. Interlocks should be in place to monitor x-ray production/distribution from dump, over-focusing magnet current and temperature, dump level vacuum.

The total of all Risks is $300k.